LIFE IN FRESH WATER

BY

E. S. BROWN

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LIFE IN
FRESH WATER

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SOME FRESHWATER ANIMALS AND PLANTS

1. Alder-fly
2. Sweet Flag
3. Caddis-fly
4. Water-measurer
5. Water-lily
6. Damsel-fly
7. Pond-skater
8. Mayfly
9. Dragonfly
10. Empty case of Dragonfly
11. Backswimmer
12. Water-beetle Larva (Dytiscus)
13. Frog Tadpole
14. Water-beetle Larva (Acilius)
15. Pond Snail
16. Smooth Newt
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18. Caddis-fly Larva in case
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ACKNOWLEDGEMENTS

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WHAT THIS BOOK IS ABOUT

THE words 'fresh water' are included in the title of this book. Everybody knows that they refer to inland waters as opposed to the salt water of the sea, and that there is a great wealth of animal and plant life in the water, of different kinds from those found in the sea. But to many people the words 'fresh water' conjure up a vision of beautiful lakes or rivers lined with willows and a variety of waterside flowers, such as marsh marigold and meadow-sweet, and they forget that 'fresh water' also includes the water of small ponds and ditches, and even such insignificant things as drinking-troughs, water butts, and puddles which collect in holes in trees and in the hoof-marks of cattle. There are plants and animals to be found in these too, quite as interesting as those in the more picturesque places, if you are prepared to spend a little time and trouble in collecting and examining them. It is important to realize this, because in studying animals and plants and their ways of life it is essential to examine them, so to speak, 'in the flesh', and not merely read books about them. Even people living in the middle of a town, and rarely seeing a river, can make opportunities of doing this; a small pool built in the back garden, or even a tin bath full of water put out in an exposed place for a few weeks in spring or summer, will collect a surprising number of living things in it. In the height of summer I once collected 128 water-beetles in 18 days in a hip-bath only about 3 feet across. The aquatic larval stages of gnats or mosquitoes and various kinds of midges are often found in thousands in rain-water tubs; and if you examine the water or the debris on the bottom of the tub with a microscope, it will reveal the presence of a great many other living things.

This brings us to the range and variety of living things which are to be found in fresh water. The average person, if asked to make a list of those he knew, would probably think first of fish, frogs, and tadpoles, otters, ducks, and pond snails; these are the things one can see without probing or making any special effort, in the course of an ordinary stroll beside a river or lake. He may also perhaps think of crayfish and some of the smaller things such as the larvae of caddis-flies and dragonflies. But the larger animals, although of great interest and in some ways more exciting, form only a small fraction of the whole. The greatest numbers, both in species, or kinds, and in individuals, are found among the more lowly creatures: certain adult insects such as water-boatmen and water-beetles, and the larval stages of many others, such as mayflies, dragonflies, caddis-flies, and a great variety of two-winged flies, are often exceedingly abundant in ponds. Crustaceans are represented far more often by minute creatures such as water-fleas than by larger ones such as crayfish; true worms, flatworms, and small kinds of molluscs (snails and mussels) are often much in evidence. All these things can be seen without any artificial aid if you look carefully. But a great number of other living creatures cannot be seen with the naked eye. If you want to be impressed by large numbers of individuals, just look through a microscope at the water of a puddle which has been standing in a farmyard for some time; the concentration of microscopic creatures swimming actively about is sometimes staggering. Most of these minute living organisms are so small that each consists of one cell only. (Cells are very small particles of living substance, and are the 'bricks' of which

the bodies of larger animals and plants are built up; our own bodies contain many millions of them.) The one-celled animals are called protozoa; there are also one-celled plants (some of the smaller algae), and they play an extremely important part in the economy of freshwater life.

The smaller forms of life are much more widespread in nature and more easily caught and examined than, for instance, fish; for every pond which contains fish there are probably a dozen or more which do not. Moreover, the smaller creatures show more variety, and illustrate the characteristic features and ways of life of aquatic organisms quite as well as larger ones, and often better. Much space will therefore be given to them in this book, so that a wider range of readers may be able to find for themselves the animals and plants which are described.

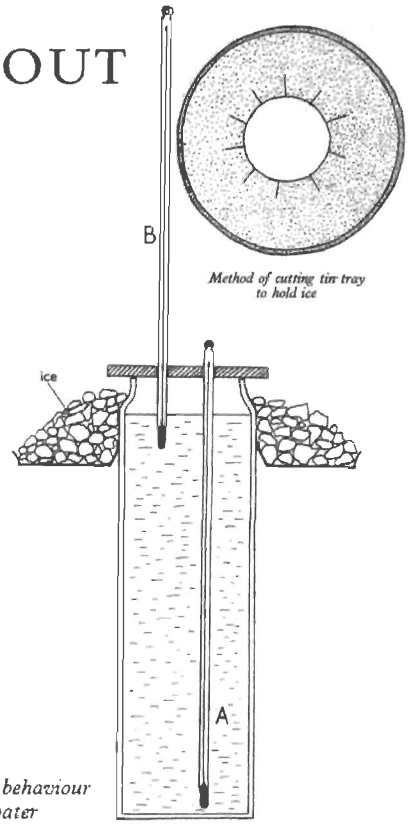
Animals and plants are classified by biologists into groups, according to the degree of relationship in their structure and anatomy. Many books on natural history describe them under the groups in which they belong, the text of the book working right through the classification so that the reader can easily identify what he finds. Although this is not by any means the purpose of this book, it will be a matter of interest to many to be able to place their captures at least in one of the main groups, and the section at the end (p. 53) will make this possible in most cases. However, as it is not possible to include all species which may be found, there are references on p. 64 to other books which will take you further if you are interested in this side of the subject.

This book describes the ways and means of life of the inhabitants of fresh water: how they are fitted to breathe, move, feed, and carry out all their other activities under the particular conditions in which they live. This idea of adaptation to a particular mode of life needs a little examination. Anyone first trying to swim soon sees that he cannot make progress by the same series of actions as he uses for walking on land. Man is not built for living and moving in water, and although, by deliberately changing his methods and practising a great deal, he can make some headway, he never becomes as efficient as, for instance, a fish. Again, a swimmer who submerges his head soon finds that he cannot breathe as he can in the air—and in this case no amount of practice will improve matters. A fish can use the small amount of air which is dissolved in the water; we cannot do this, but must have ordinary air in the form of a gas. The whole structure of our breathing system, with nose, windpipe, and lungs, is very well adapted for taking in air and getting the oxygen out of it, just as a fish's system, with gills and gill-slits, is suited for extracting the oxygen dissolved in water. Each different kind of animal or plant is adapted in all sorts of ways such as these for living in a particular set of conditions or 'environment', and fares badly in others; a fish out of water is even less at home than a man in it.

'Ecology' is a branch of natural history concerned with the relation between living things and their environment; it has come to be realized more and more how very susceptible organisms are to quite small differences and changes in their surroundings, and such differences determine which kinds can survive and flourish in any particular set of conditions. In no sphere of life is adaptation to environment better illustrated than by the animals and plants of fresh water. But even the conditions in fresh water show great variation in details; the water may be running or still, deep or shallow, clear or cloudy. We shall try to show, among other things, the sort of effect which such differences have on the community of living things which inhabit a particular locality.

IMPORTANT FACTS ABOUT WATER

WATER has certain properties which make it possible for animals and plants to live in it. To begin with, pure water is neutral (neither acid nor alkaline), and has no noxious or poisonous properties which would make life as we know it impossible. Secondly, it has a density (a mass in comparison with its volume) which is nearly the same as that of protoplasm (the living matter of which organisms are made up); indeed, protoplasm is very largely made up of water, and naturally has about the same density. Thus animals have little tendency to rise or sink, as would happen if the liquid was much heavier or lighter than they, and so their movements are not hampered. Thirdly, water is transparent, so that submerged plants can get the sunlight which they need, and those animals which have eyes can see their way about.

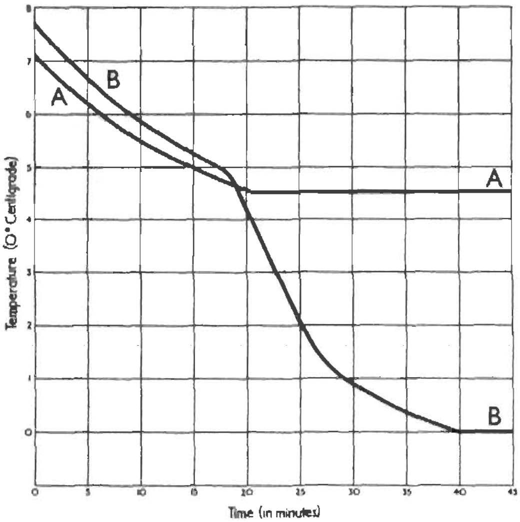


Method of cutting tin tray to hold ice

Testing the behaviour of cooling water

Apart from these rather obvious properties, there are two less well known but very important ones. One concerns the way in which water freezes. When liquids (or any other substances for that matter) are cooled, they contract or get smaller; this means that the same volume of water will now have more packed into it than before, and will therefore weigh more. The water on the surface of a pond, being exposed to the cold air, cools first; it contracts, gets heavier, and sinks to the bottom. Then warmer water rises from below to take the place of the colder water, and in turn gets cooled and sinks. This will go on until the water approaches the freezing-point (0° C.), the water at the bottom always keeping a little cooler because that at the surface has not had time to cool down. Now if water behaved as other liquids, this would go on until all the water in the pond was down to freezing-point, and it would all freeze together to form a solid block. Any animals living at the bottom (and this is where most of them live and get their food), would fare ill in face of such a disaster. Although some animals can survive being frozen in solid ice for a time, many cannot. But water does not behave as other liquids, because when cooled it contracts and gets heavier only as far as 4° C.; on further cooling it expands again and gets lighter. This means that when the surface water is cooled below 4° C., it does not sink, but remains where it is at the top until it freezes at 0° C., while the heavier water at the bottom will stay at the same temperature about (4° C. or 5° C.), without freezing. And so a pond or lake freezes from the surface downwards, and only very rarely is frost hard enough and long enough for the ice to extend more than a few inches in depth.

These facts can easily be tested with the simple apparatus shown in the diagram. The neck



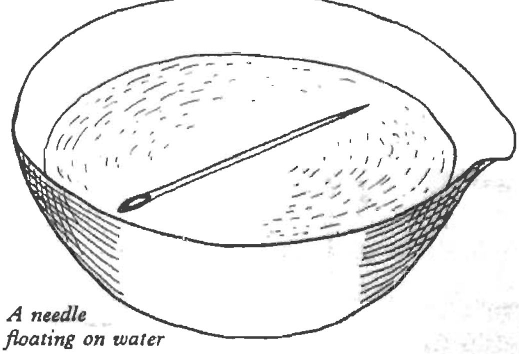
of a jar of water is surrounded by ice. The water is cooled by the surrounding ice, and the temperatures are read at one-minute intervals on thermometers *A* and *B*, which record the temperatures at the bottom and at the surface of the water respectively. A graph can then be drawn for easy comparison of the cooling process at the two levels. The graph illustrated shows the results of one such experiment which took 45 minutes to complete.

Because ice forms first over the surface of ponds or lakes, living things can keep active in the not too cold water below. By lying flat on the ground and looking through clear ice on a frozen pond in January, it is possible to see water-beetles, water-boatmen, and other creatures swimming about quite normally.

The other special property of water concerns its surface. At the surface of a liquid the molecules—the minute particles of which substances are made—are unusually strongly attracted towards each other, and this gives the extreme surface layer, called the 'surface film', a certain strength, so that it behaves as a sort of elastic skin. It is this which keeps a drop of water unbroken as it falls from a tap. Some liquids have a much stronger surface film than others. Water has a particularly strong one, and this is very important to many freshwater animals, and will be referred to frequently in this book.

The existence of the film can be demonstrated quite simply. If, using forceps, we place very carefully on to the surface of a dish of clean water a long, thin needle which has been thoroughly cleaned of all grease and dried, contrary to expectations the needle will float, because it is held up by the surface film. A careful investigation will show that there is a dimple in the film due to the needle's weight. It is easy to prove that although it is floating the needle is really heavier than water, for if we press it downwards at one end with the forceps, enough to force it below the surface, it will immediately sink, since it no longer has the support of the surface film. Some other liquids, such as methylated spirit, for example, have not such a strong surface film, a fact which can be tested by repeating the experiment with methylated spirit.

Another simple experiment to illustrate the surface film is to push a piece of velvet with a stiff, close-set pile under water. The surface film is so strong that the water will not penetrate between the hairs of the pile, which will therefore retain a layer of air and give the velvet a silvery appearance. For the same reason a submerged water-spider has a shiny, silvery appearance, for its body has a covering of hairs much like the pile on velvet. We shall see later on how very important this surface film can be in the lives of many of the smaller aquatic animals.



A needle floating on water

METHODS OF STUDY

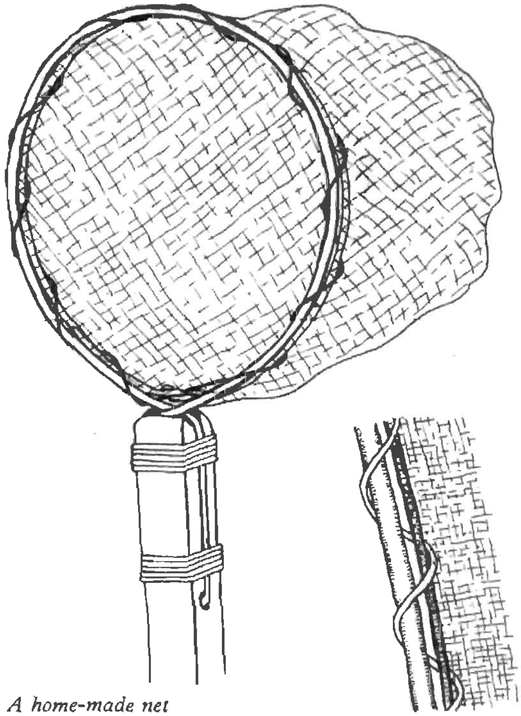
It is important before going any further to know something of the best ways of collecting and examining the creatures which are described in this book.

Collecting

Most freshwater animals must be caught in a net. A useful type which can be made very easily is illustrated. A wire ring, of galvanized iron or other metal which will not rust, and stout enough to be forced through the weeds of a pond without bending, is bound on to the end of a strong handle. The mouth of the bag is sewn round another ring of the same diameter (about 6 or 8 inches is a convenient size), which need not be made of such thick wire. The two rings are then bound together with thin, flexible, copper wire, with a point at one end, which can be threaded through the material of the net and wound spirally round the two rings. The double-ring arrangement is much better than sewing the net directly on to a single ring because the leading ring gives extra protection to the material of the net so that it does not wear out when worked through weeds or the mud or gravel on the bed of a pond or stream.

The bag should be made of a material with a coarse enough mesh for water to pass through easily; nylon is more expensive than muslin or hessian, but lasts longer because it does not rot so easily. For collecting microscopic life floating in the water (called plankton) a special net is useful, and this must be made of very fine silk; if a glass tube is fitted into the apex of the bag, a concentrated suspension of microscopic organisms collects in it as the net is swept through the water.

The net should be forced through growths of water-weeds, with repeated sweeps over the same track, working the net backwards and forwards, because later sweeps catch the animals disturbed and stirred up by earlier ones. In fast-running water most of the smaller animals are attached to or under the stones, and these should be churned up with the foot while the open net is held downstream.



A home-made net

The catch is taken home in glass tubes, jars, or tins containing as little water as possible; if a tube is filled right up with water and corked, the animals in it will quickly suffocate for lack of oxygen. Experience soon teaches one not to put strong, voracious animals such as the larger water-beetles into tubes together with more tender, fragile creatures such as mayfly larvae.

Before leaving a pond, it is a good plan to collect a net full of weeds and gravel and silt from the bottom and take it home in a tin; if it is then put into water in a dish or large glass jar, the number and variety of smaller forms of life which appear when the water has cleared is often astounding.

Animals collected in this way will not usually survive very long unless they are kept in a properly set up aquarium, where they can be observed over a long period and their habits and life-histories studied more thoroughly than is possible from random outdoor observations.

It is important to imitate the natural conditions of the pond or stream as nearly as possible, as the inhabitants are more likely to survive and to behave in a normal manner in such circumstances. A good method of setting up an aquarium is to put 2 or 3 inches of garden soil into a rectangular glass tank, and to plant some aquatic vegetation in it; rooted plants such as water buttercup, water milfoil, water starwort, hornwort, and Canadian pondweed are very good, and the foreign plant *Vallisneria*, obtainable from dealers, is excellent; species of *Potamogeton*, and plants which grow up out of the water, such as arrowhead and water plantain, are very ornamental if the tank is large enough. A thickness of half an inch or more of good silver sand (obtainable from ironmongers), which has been thoroughly washed in running tap-water overnight, is then spread over the soil, so that the water does not become fouled by direct contact with the soil, and the animals have a clean floor to live on, with the plants sticking up through the sand into the water. The water is carefully poured on to a glass plate laid flat on the sand so that it does not disturb the sand. The plants will grow and keep healthy for a long time since their roots draw nourishment from the soil, but they must be thinned out from time to time to prevent the water getting choked. It should be unnecessary to change the water except at rare intervals, provided it remains clean and unclouded.

There are three main points to be considered in managing an aquarium—the provision of air and of light for the aquarium and the planning of a biologically 'balanced' community in the aquarium.

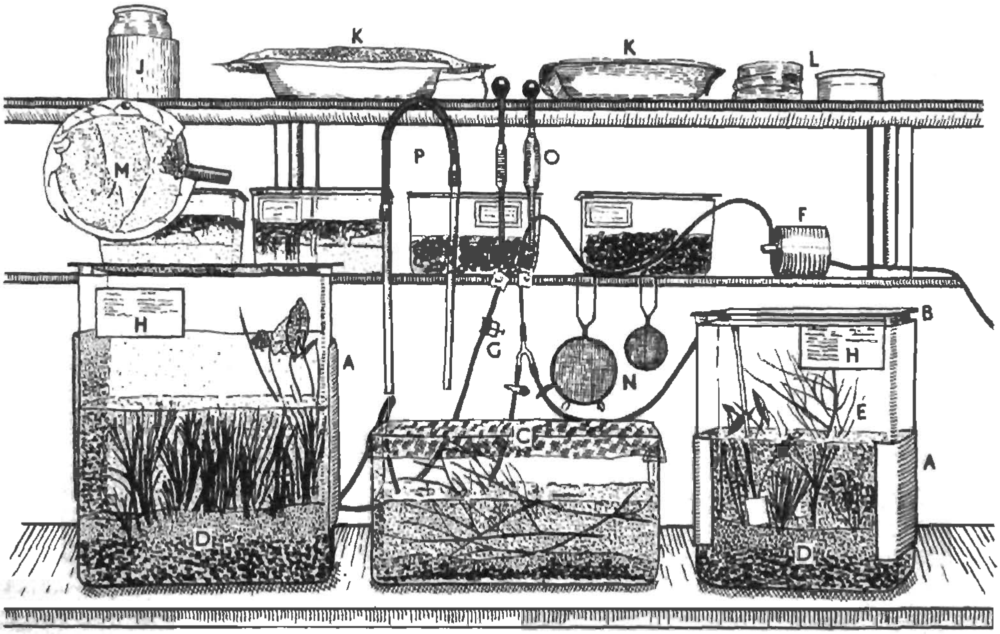
1. *Aeration.* The oxygen which organisms extract from the water comes originally from the atmosphere. A low tank with a wide area of shallow water will therefore give better aeration than a tall one with a small area of deep water, because the water presents a bigger surface area to the atmosphere in relation to the quantity of water present and will dissolve more oxygen. A stream of air bubbles passed through the water has the same effect, and this is the principle of an electrical aerator. This, although more expensive than home-made mechanical devices and not absolutely essential, is a great asset, since it will aerate several tanks at the same time. The best aerators of all are the green plants themselves, for oxygen is a by-product of their activities; if, therefore, there are plenty of healthy plants in the aquarium, a natural aeration takes place.

2. *Light.* For the feeding and health of plants sunlight is essential. The direct rays of the sun, however, overheat the water, which is not healthy for animals which are accustomed to lurking in the gloomy depths at the bottom of a pond or river. The aquarium, therefore, should have just enough light for the plants and not too much for the animals. This can often be achieved by growing a limited and carefully regulated blanket of duckweed on the surface, or by screening about two-thirds of the glass by some opaque material. In the natural state in the pond, of course, light comes only from above.

3. *A biologically 'balanced' system.* It is unwise, obviously, to keep predacious animals such as large water-beetles, dragonfly larvae, or perch in the same tank as, for instance, small harmless fish or water-boatmen on which the former prey. Either they must be given food regularly, or, in the case of smaller organisms, it is possible to build up a balanced, or interdependent, system which to a great extent keeps itself going, the soil forming the basic fodder on which all are indirectly dependent. A study of the 'food-chains' illustrated on pp. 24 and 25 will

show what sort of effect one may expect from the introduction of a number of different animals. Small crustacea should be encouraged, since they form a food basis for most animal communities containing carnivorous species; *Daphnia* can usually be obtained in large numbers, or cultured in a separate tank by adding a few drops of decaying egg-yolk solution to the water at intervals, for they eat the bacteria which live on the egg. Experiments on the interrelations between different organisms in a community will give interesting and valuable results. One can experiment on chemical and biological 'control': for instance, a trace of potassium permanganate will discourage 'blanket weed' (*Spirogyra* and other thread-like algae), and fish can usually be cured of the dreaded *Saprolegnia* fungus disease, if it is not too firmly established, by removing them for a time to a tank containing a tablespoonful of salt to two gallons of water. The microscopic algae which grow on the glass and obscure the view can be checked by snails, but if there are too many snails they will eat the larger plants as well.

A running-water aquarium. Animals found in rapid streams, such as *Simulium* larvae, require special treatment and will seldom survive long in an ordinary aquarium, however well the water is aerated. A running-water aquarium can be made with a series of enamel dishes one above the other on slanting shelves, so that a trickle of water run into the top dish will overflow into the next one below it, and so on, the same stream sufficing for several dishes. Covers of muslin (nylon is more durable) stretched on wire frames will prevent animals escaping from one dish to another.



Apparatus for keeping aquaria

A. Brown paper round three sides of tank to cut out excessive light
B. Glass cover raised on corks to allow access of air
C. Perforated zinc cover
D. Soil base covered with silver sand
E. Twigs for emerging insects to crawl up
F. Electric aerator
G. Screw clips to control air
H. List of animals and plants in the tank
J. 'Jam jar' aquarium with brown paper sleeve
K. Pie dishes with muslin covers
L. Dishes for microscopic or other examination
M. Water net for collecting
N, O. Wire gauge strainers and pipettes for transferring animals from one dish to another
P. Siphon for emptying tanks and removing fine debris

THE ORIGINS OF FRESHWATER LIFE

THE first living organisms to inhabit the earth must have been aquatic, because the simplest forms of life could hardly have existed on the barren rock which then constituted the dry land. Probably the sea, rather than fresh water, was the cradle of life, but of this we cannot be sure; the sea may not have been so different from fresh water as it is now, for it has been gradually accumulating more and more salt through the ages, and it may have contained very little when life first appeared.

The animals and plants of fresh water may have originated in three ways: (1) they may have been first produced in fresh water as new forms of life ('archaic' types); (2) they may have invaded it from the sea, or (3) from the land. There are very few animals (salmon and sea-trout are amongst them) which can survive a change from salt to fresh water or vice versa during their lifetime, unless the change is carried out gradually in a series of small steps. The term 'invasion' is used here to denote small evolutionary changes by which an organism adapts itself to different conditions. Evolution is the cumulative effect of almost imperceptible changes through many generations, often taking thousands or millions of years, which may make possible a change of environment as great as that from sea water or even from the land to fresh water.

1. *Archaic types*. Very probably some of the simplest organisms, such as certain protozoa and single-celled algae, had their origin in fresh water as opposed to the sea, but we cannot be certain of this. The amphibians (frogs, toads, and newts) are the modern descendants of a very ancient group which may have made its first appearance in freshwater marshes and swamps. The stoneworts are of uncertain origin, but very possibly are descended from green algae in fresh water.

2. *Invaders from the sea*

Protozoa (some at least)	Algae (some at least)
Coelenterates (*Hydra*)	Snails (some)
Flatworms	Crustacea
	Fishes and Lampreys

3. *Invaders from the land*

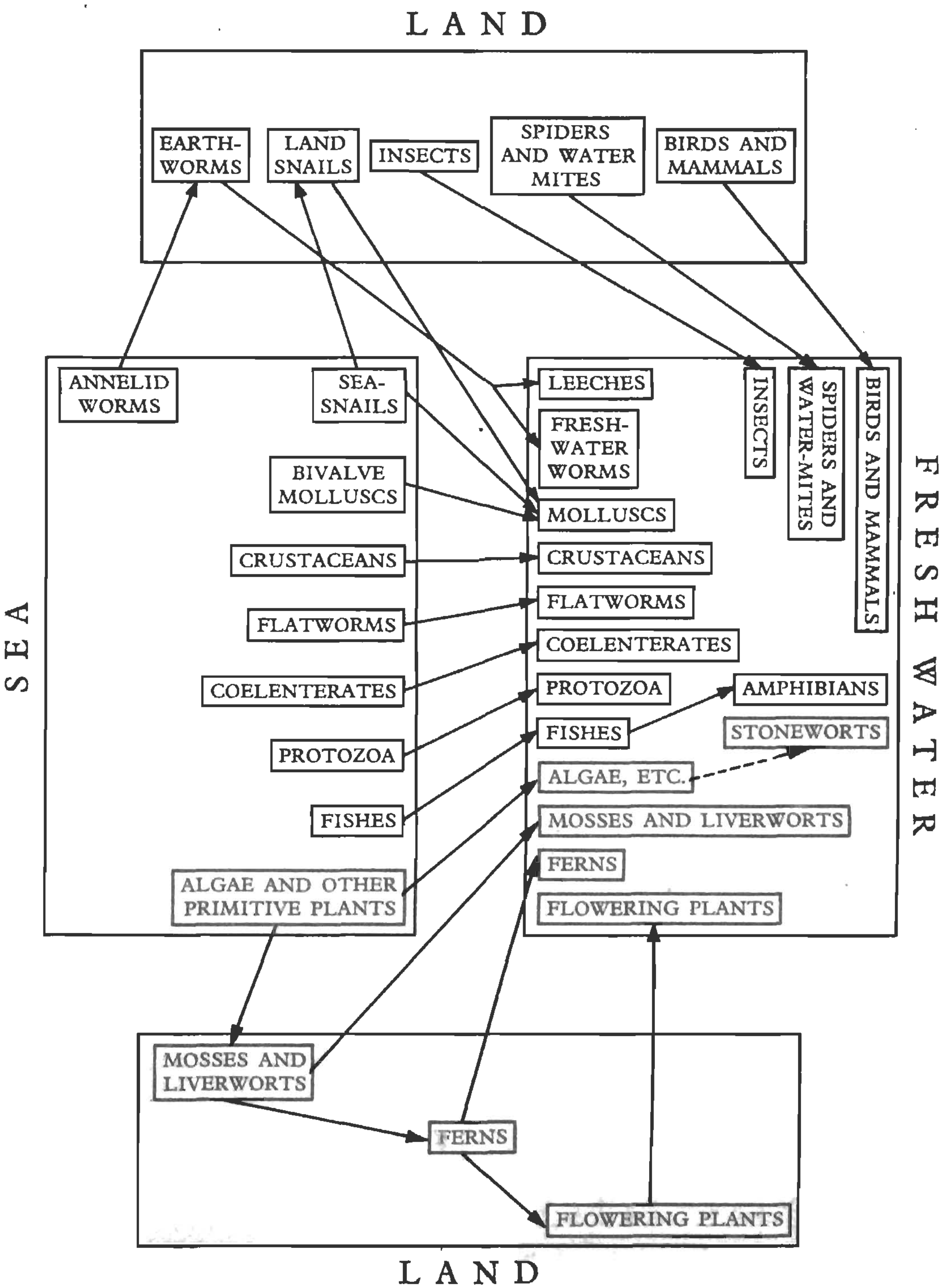
Freshwater worms (Annelids)	Water-spiders
Leeches	Water-mites
Snails (some)	Birds and mammals
Insects	Flowering plants and ferns

The insects form much the most conspicuous part of the fauna which has come from the land.

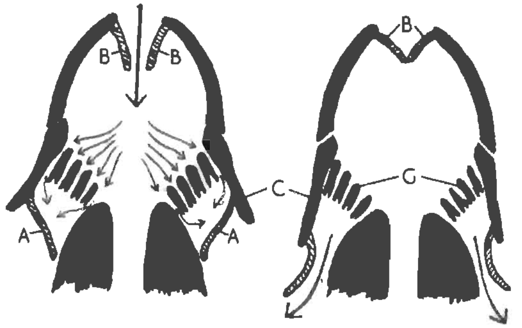
As these invasions occurred millions of years ago, it is often difficult to deduce just what happened. In general, organisms with a more complicated structure are derived from simpler ones, but sometimes it is possible that a process of simplification has taken place in evolution; this may have happened in the freshwater worms, which, although simpler in some ways than earthworms, yet have features which suggest that they were derived from them instead of giving rise to them.

There is an important distinction between 'primarily' aquatic forms of life, which originated in water (either fresh or salt), and 'secondarily' aquatic forms which colonized water from the land. This difference in origin has much to do with the ways in which they have become adapted to aquatic life, and to the degree of perfection which their adaptations show.

The chart opposite shows the probable origin of freshwater animals and plants.


LAND
EARTH-WORMS
LAND SNAILS
INSECTS
SPIDERS AND WATER MITES
BIRDS AND MAMMALS
SEA
ANNELID WORMS
SEA-SNAILS
BIVALVE MOLLUSCS
CRUSTACEANS
FLATWORMS
COELENTERATES
PROTOZOA
FISHES
ALGAE AND OTHER PRIMITIVE PLANTS
FRESH WATER
LEECHES
FRESH-WATER WORMS
MOLLUSCS
CRUSTACEANS
FLATWORMS
COELENTERATES
PROTOZOA
FISHES
ALGAE, ETC.
MOSSES AND LIVERWORTS
FERNS
FLOWERING PLANTS
INSECTS
SPIDERS AND WATER-MITES
BIRDS AND MAMMALS
AMPHIBIANS
STONEWORTS
MOSSES AND LIVERWORTS
FERNS
FLOWERING PLANTS
LAND

BREATHING UNDER WATER



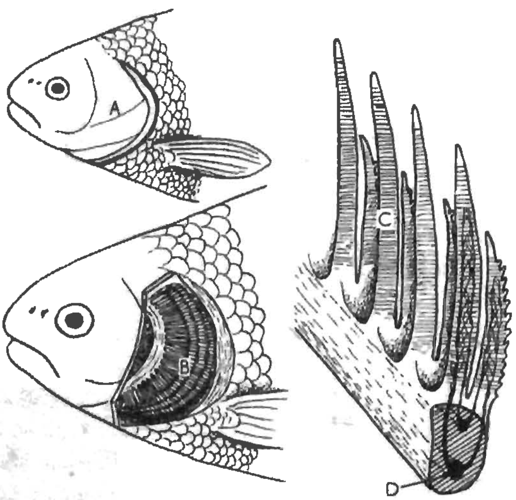
The breathing process of a fish
Left: *When water is drawn in at mouth and through gills* (G), *gill-covers* (C) *are moved outwards and valves* (A) *closed*
Right: *When water is expelled through valves* (A), *gill-covers are moved inwards and mouth valves* (B) *closed*

RESPIRATION (which means almost the same as breathing) is so essential to all living things, plants and animals, that it profoundly affects their structure and activities. Normally, it involves the taking in of oxygen and giving out of carbon dioxide and the provision of a steady stream of energy which an organism needs to keep active. Plants respire, but since animals are more active and need more energy, their breathing apparatus is more conspicuous.

Human beings, like other land animals, obtain oxygen through their lungs from the atmosphere, of which it forms about one-fifth by volume. The oxygen is transported here and there in the body by the blood-stream, and used wherever it is wanted at the moment. An aquatic animal living entirely under water cannot obtain oxygen from the atmosphere, and must use that which is always dissolved in natural waters exposed to the air. If caddis-fly larvae or mayfly nymphs, for example, are put into water which has been boiled and then cooled out of contact with air, they will show signs of discomfort and, unless air is bubbled through the water before it is too late, will eventually die for want of oxygen.

Oxygen is absorbed through a soft, thin membrane which in land animals, because it has to be kept moist, is generally internal, as in the lining of lungs or of the breathing tubes of an insect. Aquatic animals, being permanently wet, can, and usually do, absorb the dissolved oxygen from the water through external respiratory membranes such as those covering the gills of a young tadpole. In small animals the whole surface of the body may absorb oxygen.

Terrestrial and aquatic animals have had to become adapted to breathing in rather different ways. The earliest animals in existence, being aquatic, practised underwater breathing; those that later came to live on land had to tuck their respiratory membranes away inside their bodies where they could be kept moist enough to do their job. Evolution, however, has taken some curious turnings, and some of the land animals later returned to the water, which meant that the system which had become adapted to aerial



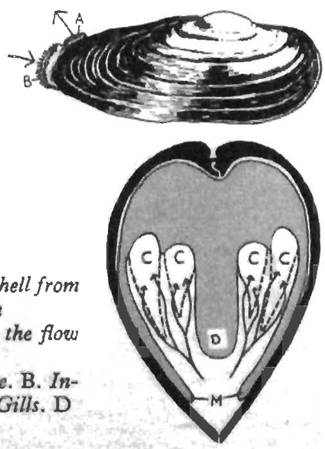
Respiratory system of a typical fish (*Roach*)
A. *Gill-cover*. B. *Gills exposed by removing cover*
C. *Gills*. D. *Blood vessel*

respiration had to be altered again so that it would function in the water. Thus the distinction made earlier between 'primarily' and 'secondarily' aquatic animals separates two types which have evolved their breathing systems in fundamentally different ways.

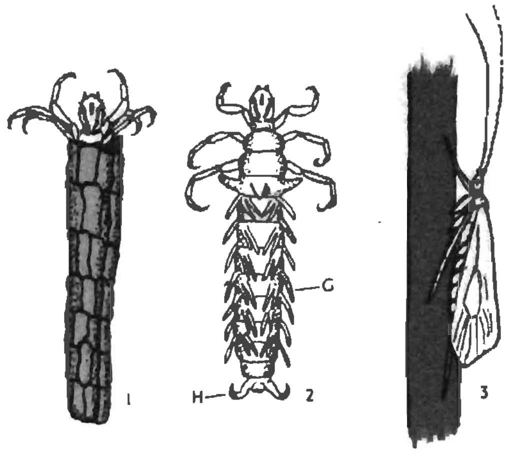
The breathing apparatus of primarily aquatic types usually consists of some form of blood-gill, the gill extracting the oxygen and the blood distributing it. In the simplest animals the whole surface of the body is the gill. In higher types two things occur: (1) a special structure or area of the body is developed for respiration and the surface area of the membrane is increased, for example by folding, and (2) a method is developed for propelling a current of water over the membrane so that fresh water is kept in contact with it.

A fish breathes by taking in water at its mouth, passing it over the gills and out by the gill-slits. The membrane lining the gills is folded to give a larger surface for absorbing oxygen, and the current of water is maintained by active movements of the mouth, with the help of flaps of skin which act as valves.

The gills of freshwater mussels are flaps of soft tissue which hang down like curtains, two on each side of the animal, within the two halves of the shell. Their walls are cut up by many slits, the whole resembling the grating over a drain. Water enters the shell through a hole at the



Freshwater mussel: shell from right side and section
The arrows indicate the flow of water
A. Exhalant aperture. B. Inhalant aperture. C. Gills. D Foot. M. Mantle



Caddis-flies: 1. *Larva of* Phryganea *in case and* 2, *removed from case.* 3. *Adult* Limnophilus. G. *Gills* H. *Hooks for hanging on to case*

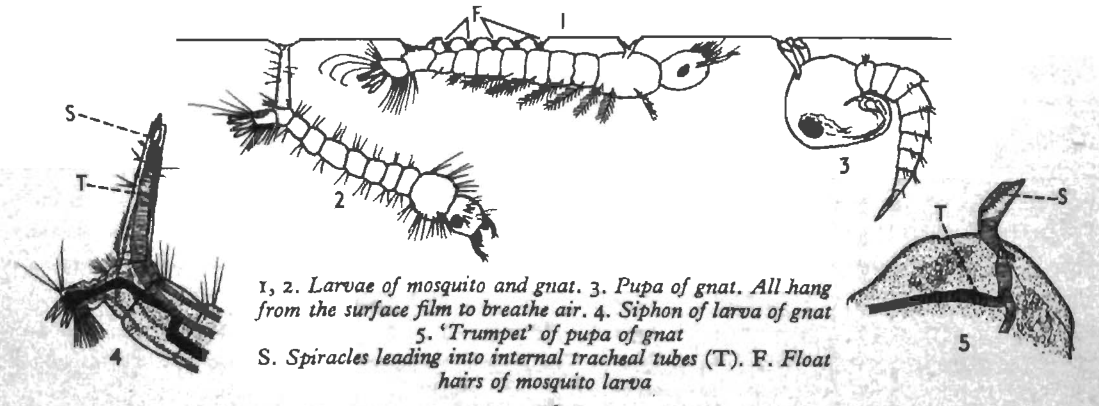
hind end and is pushed through the slits by the beating of innumerable thread-like hairs, called 'cilia', which line them. It passes out again through another hole. These movements can be seen quite clearly if a little carmine or Indian ink is added to the water through a tube. The total surface of the respiratory membrane lining the slits is very large, and blood running down inside the partitions between the slits carries off oxygen to the different parts of the body.

Breathing movements are usually regulated according to the amount of energy the animal needs at the moment, or according to the amount of oxygen dissolved in the water. A simple experiment will show this. A caddis-fly larva, having been goaded out of its case by inserting a pin gently into the rear end, is put in clean water in a small vessel with nothing but fragments of broken glass. The larva will usually make a new transparent case out of the glass, through which its movements can be watched. Now and then it makes undulating movements with its body to drive a current of water over the thread-like gills. In well-aerated water these movements may be infrequent, but in water previously boiled to drive off the oxygen, they will become continuous and quite violent.

When systems evolved for one mode of life have to be adapted for use in another, we find the most interesting and often grotesque forms

of life. The secondarily aquatic animals provide excellent examples, the most conspicuous being among insects, which appeared first on the earth as terrestrial forms of life. The breathing apparatus of a typical land insect consists of a branching network of tubes inside the body, called 'tracheae'; their finer branches pass to all the parts and tissues of the body, and the tubes open to the air through a row of small holes down each side, called 'spiracles'. A trachea is prevented from collapsing by a spiral of hard material, like the spiral of wire which is sometimes put into rubber hosepipes. Air can thus enter the spiracles and get access to every part of the body, oxygen diffusing from the finer branches of the tracheae into the tissues and carbon dioxide being evolved. Insects often regularly contract and expand their bodies, so circulating the air and pumping it in and out of the spiracles; these movements can be easily seen if a wasp is watched closely when it is eating jam.

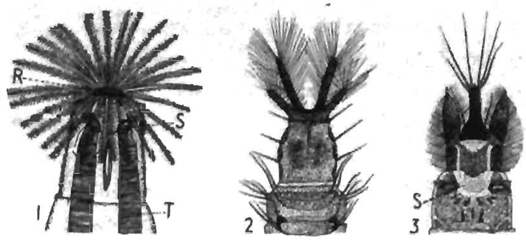
Many of the insects which have returned to the water have never altered their respiratory apparatus, but have continued to breathe atmospheric air. Water-beetles and water-boatmen, for instance, have to make frequent visits to the surface, as can easily be seen by watching the surface of almost any pond. Animals which breathe like this (whales are amongst them) are called 'false aquatics', in contrast to 'true aquatics' which can breathe dissolved oxygen and spend all their time under water. False aquatic insects often have devices which enable them to remain stationary at the surface film while they exchange used air for fresh. For instance, the larvae of gnats, known as 'wrigglers', can be found in shady pools and rain-water butts, where they feed on microscopic plants called algae. They rise at intervals to the surface and hang for a time while they renew their air supply through siphons—tubes which extend from the hind end of their bodies. The siphon has a hole at the tip leading into a pair of spiracles, which open into two tracheae which run down the siphon and forward to the front of the body. The opening is surrounded by five triangular valves, which close firmly together when the larva is under water, but open out the moment the tip of the siphon breaks the surface, so that air can pass through the spiracles and along the tracheae. The larva is heavier than water and has to make wriggling movements to rise to the surface, but once the valves have opened it is held there. The outer surfaces of the valves are said to be 'hydrophile', that is, they are attracted to and readily wetted by water, and they are therefore drawn outwards and downwards on to the surface film of the pool; their inner surfaces, on the other hand, are repelled by water and cannot be wetted by it, so that the spiracles in the centre remain dry. The weight of the larva pulls the surface film downwards, so that a dimple is formed with the spiracles in its centre. The larva of the mosquito (*Anopheles*) is similar but has no siphon, and the spiracles are flush with the surface of the body. The pupae of all



1, 2. *Larvae of mosquito and gnat.* 3. *Pupa of gnat. All hang from the surface film to breathe air.* 4. *Siphon of larva of gnat* 5. *'Trumpet' of pupa of gnat*
S. *Spiracles leading into internal tracheal tubes* (T). F. *Float hairs of mosquito larva*

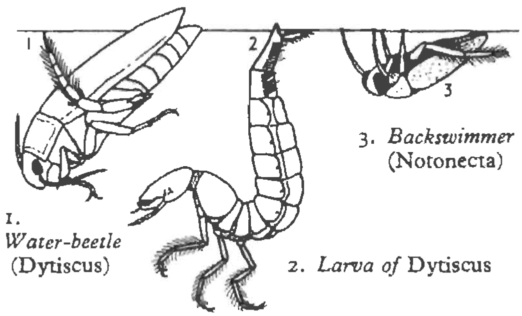
kinds of mosquitoes have respiratory 'trumpets' at the front end; they are lighter than water and can spend most of their time at the surface because in the pupal stage the insect does not feed.

The much larger larvae of chameleon-flies also have spiracles at the hind end; they are surrounded by a circlet of threads edged on both side with hairs. When the larva is at the surface, these threads extend outwards like a star, anchoring the larva to the surface film and throwing the spiracles open to the air. When the larva pulls away from the surface, the threads curve inwards, enclosing an air bubble which acts as a reserve while the larva is under water. The larvae of psychodid flies and of the gnat *Dixa* breathe in very similar ways.

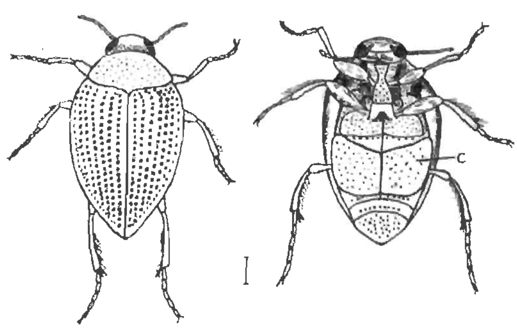


Hind ends of larvae of (1) *Chameleon fly with fan of respiratory hairs.* (2) *Psychodid fly with hairs surrounding respiratory opening.* (3) Dixa *with hairs which support it at the surface film*
R *Respiratory opening.* S. *Spiracles.* T. *Tracheal tube*

Unlike the gnat larva, most air-breathing insects are lighter than water, so that they rise without effort to the surface. The larva of the Great Water-beetle (*Dytiscus*) has its spiracles on a small turret at the hind end. This protrudes a little above the surface, and a pair of little hair-fringed, finger-shaped objects called 'cerci' flatten out along the underside of the surface film, making an angle with each other, much as our feet do; the larva, in fact, stands in what we would call an upside-down position on the surface film. The cerci keep it steady while it takes in air and keeps watch for prey. The 'backswimmer' (*Notonecta*) rises upside down, true to its name, and uses the tips of its two front pairs of legs to hold it steady against the surface.

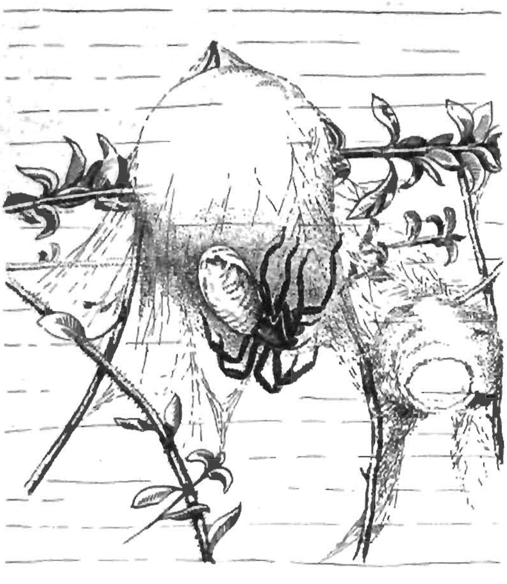


Insects breathing at the water surface



Haliplus, *a water-beetle which keeps part of its air-store under the coxal plates* (C) *on the underside*

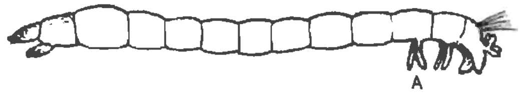
Air-stores carried outside the body, like the bubble of the chameleon-fly larva, enable an animal to remain under water for a considerable period, and only to make short visits to the surface, for it takes less time to refill an external bubble than an internal network of tracheae. Full-grown water-beetles and corixid water-boatmen have air-stores under the wing-cases, which are renewed in a fraction of a second when the insects swim to the surface and expose the tip of their abdomens. Hydrophilid beetles, water-boatmen, and several other insects have in addition a coating of short hairs on their undersides, like the pile on fine velvet, which when submerged retains a layer of air and gives the insect a silvery appearance. The spaces between the hairs are too small for the surface film to penetrate. Perhaps the most curious



Water-spider beside its diving bell

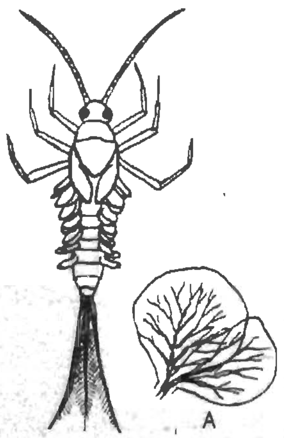
air-store of all is that made by the water-spider. It spins a small tent-like web which it attaches to plants under water and which it fills with air carried down in the hair-coat which covers its body. In this bubble it spends much of its time, living in the atmosphere which it has transported into its new home.

Constant visits to the surface, however short, are a nuisance; they interrupt the animal's feeding, and expose it to attacks from enemies such as sticklebacks, voracious dragonfly nymphs, and the like. The insect is far more likely to survive if it can avoid them as far as possible; it is small wonder, therefore, that the breathing system of a great many insects has become modified towards this end. Most of such insects are true aquatics and instead of open spiracles

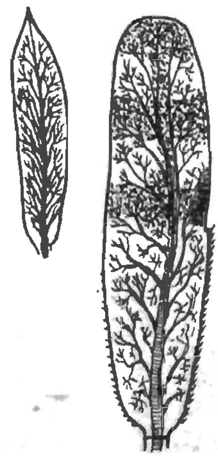


Bloodworm with so-called 'blood-gills' (A)

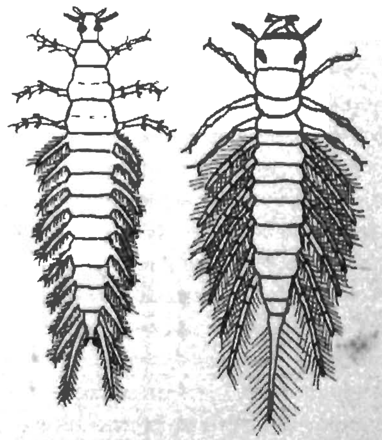
have some form of gills so that they can use dissolved oxygen. Generally they have a special type called a 'tracheal gill', which is a tubular or flat leaf-like outgrowth of the body, often branched and richly filled with small tracheal branches which are very beautiful to look at through the microscope; oxygen diffuses through the surface of the gill and into the tracheae. Mayfly and damsel-fly nymphs and alder-fly and caddis-fly larvae have gills of this type. The larger dragonfly nymphs have special 'rectal gills' in the wall of the hind end of the digestive canal, which pumps water in and out by alternately expanding and contracting. Some



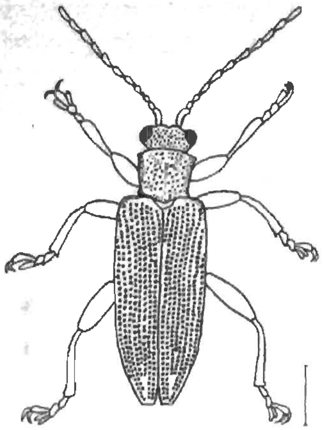
Larva of a mayfly showing tracheal gills on abdomen. A. A gill



Tracheal gills of damsel-fly nymphs



Larvae of whirligig beetle and alder-fly with gills on the sides of the abdomen



Donacia,
a Chrysomelid beetle

insects have no special gills at all, but respire through the surface of the body.

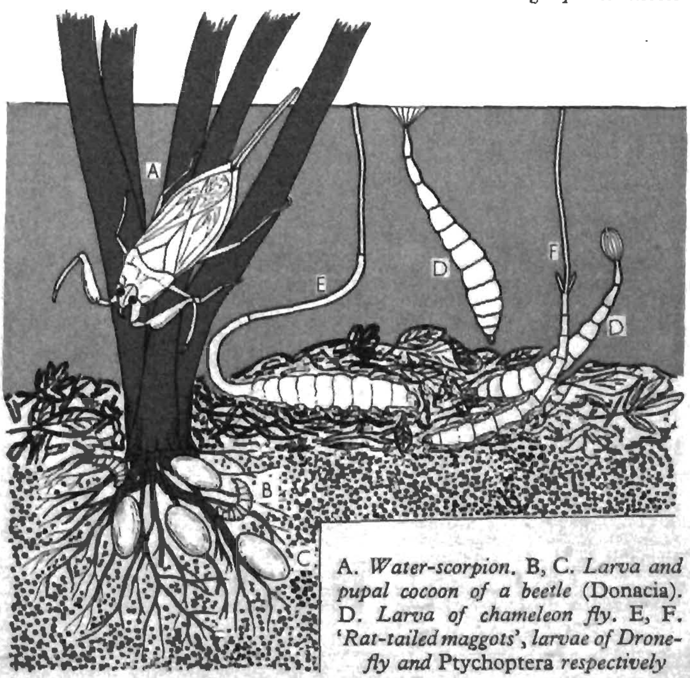
A few insect larvae, such as the 'bloodworm' larva of a midge called *Chironomus*, have evolved even further, having acquired red blood rather like that of fish and other primarily aquatic animals.

Insects with external air-stores can to some extent use these as gills. Oxygen from the water is drawn through the surface film covering the air bubble, which acts as the membrane, and diffuses through the body. A few, such as the water-bug *Aphelocheirus*, have a pile of unusually short and close-set hairs over a large part of the body, which holds a thin and permanent air film or plastron, thus enabling the animal to rely entirely on this kind of respiration.

Some of the strangest insects are those false aquatics which, although requiring atmospheric oxygen, have peculiar devices to avoid visiting the surface to fetch it. The 'rat-tailed maggot', which is the larva of the drone-fly, bears its spiracles at the tip of a telescopic tail or siphon which can be extended to 4 or 5 inches. The maggot can thus feed on the bottom in the shallow margin of a pond, with its air laid on from above. Exactly the same device has been acquired independently by the larva of another fly called *Ptychoptera*. The water-scorpion (*Nepa*) also has a short breathing tube, but it is not telescopic. The larvae of certain beetles and of a few flies (including one of the mosquitoes) tap the air spaces in submerged plants (see p. 41) to provide an underwater source of air. They have special devices for piercing the plant roots and getting the air out.

It is interesting to see that life under a special set of conditions produces similar modifications of structure in quite distinct groups of animals. This curious trick of evolution, which is called 'convergence', is very well illustrated by the respiratory and other adaptations of the secondarily aquatic insects which we have been considering.

Some air-breathing aquatic insects



A. *Water-scorpion.* B, C. *Larva and pupal cocoon of a beetle* (Donacia). D. *Larva of chameleon fly.* E, F. *'Rat-tailed maggots', larvae of Drone-fly and* Ptychoptera *respectively*

FOOD AND ITS CAPTURE

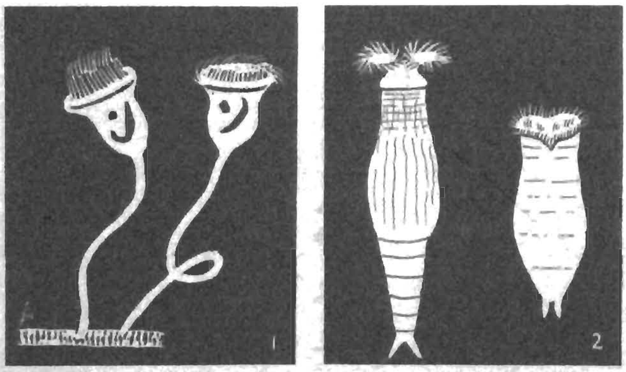
UNLIKE breathing and movement, which must be differently organized for land and water, feeding habits are fundamentally much more similar in the two spheres of life. Especially is this so among bigger animals such as fish and the larger green plants.

Some of the few animals which have obvious adaptations to aquatic conditions feed on a vast store of food which has no counterpart on land. It consists of minute plants and animals, many of them one-celled, such as bacteria, diatoms, desmids, and flagellates, which float about in the water. These free-floating, drifting forms of life are called 'plankton'; they play an important part in the economy of freshwater life, for together with minute particles of dead organic matter they form a highly nutritious food. The plankton takes a great deal of collecting, because the ordinary methods of chasing and catching prey one at a time, even if it were possible, would require far too much effort for very little result. It has to be collected in a wholesale manner, by straining a large volume of water in order to extract enough food to make it worth while. Some animals perpetually swim through the water in order to extract food from a large volume of it. *Paramecium*, like some other ciliate protozoa, thrives in farmyard puddles, swimming ceaselessly through the foul water which contains innumerable bacteria. These form the chief item on its menu. The mouth is at the bottom of a funnel-shaped gullet opening forwards, and lined with a 'vibrating membrane' which directs a current of water towards the mouth. When enough bacteria have accumulated, they are taken in through the mouth.

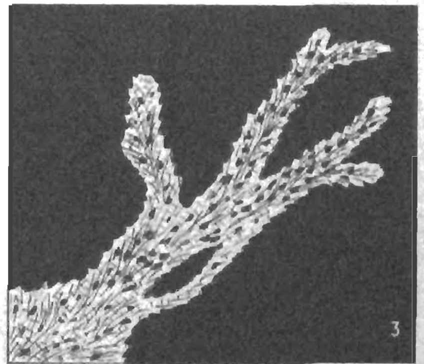
Many other small 'filter feeders' sit still in one place and cause a current of water to pass through or over them by means of cilia. Another ciliate is *Vorticella*, or the bell animalcule. It is generally fixed by a stalk to some object and has its cilia reduced to a ring round the rim of a flat circular disk at the free end. Outside the disk is a circular groove leading into the gullet. The cilia set up a current which wafts food particles into the groove and down the gullet to the mouth. Their movement is easily seen under a microscope.

Although they are many-celled and much more highly organized, rotifers have developed a ciliary mechanism very like that of *Vorticella*. The cilia produce a feeding current when the rotifers are attached to the bottom, but when they let go the same ciliary action results in movement of the whole animal.

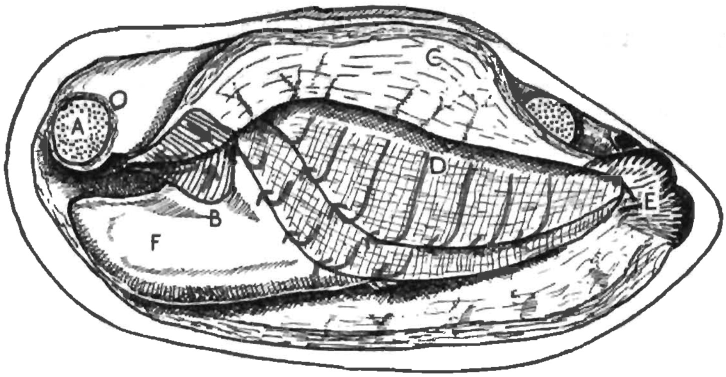
A better organization for this kind of feeding



Animals with a circlet of cilia which create a whirlpool, bringing food particles to the mouth. 1. Vorticella, *a protozoon.* 2. *Rotifers*



An unusual animal: the freshwater sponge

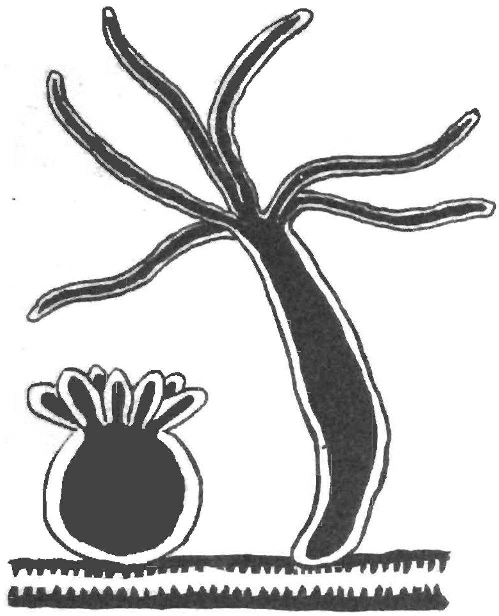


Swan Mussel with left valve of shell removed and left mantle flap turned back
Feeding currents produced by cilia are shown by arrows. A. *Cut end of muscle closing shell*
B. *Labial palps.* C. *Mantle turned back.* D. *Gills.* E. *Inhalant aperture.* F. *Foot*

is the freshwater sponge (*Spongilla*), which, like the bath sponge, has its surface full of holes; these are the openings of an intricate system of tubes running right through the inner structure. A water current, maintained by cells with special thread-like flagella lining the tubes, passes in through very small holes on the surface, and out through others large enough to see with the naked eye; minute food particles are absorbed by the flagellated cells.

The through-current of water which a mussel maintains for respiration has already been described (p. 15). It has a double purpose, for the food particles it carries are trapped and carried to the mouth by the joint action of millions of millions of cilia. The current enters the mantle cavity and is passed by the action of certain of the cilia to the inside of the gills through the small perforations in them (see diagram on p. 15). As it passes through, a film of slime secreted on the outside of the gill entraps the food particles, and other tracts of cilia conduct slime and food together downwards to the lower margin of the gill. The food is then passed forwards along the edge of the gill to a pair of flaps on either side, called the labial palps. These are grooved and ciliated on their inner surfaces. Digestible food is directed along the deep groove in between the pair of palps on each side, and forwards into the mouth, which therefore receives a perpetual stream from both sides. Undesirable particles, however, are side-tracked along 'rejection paths' to the tips of the palps; here they drop off and are caught up on the inner surface of the mantle, where they are directed backwards and out of the shell at the hind end. Altogether this is a very highly organized feeding mechanism. It enables a fairly large animal to live on microscopic food, the small size of which is made up for by the large volume of water which is passed through the system; probably the amount is not far short of a gallon every hour for a large Swan Mussel.

Certain other animals feeding on the same type of food have neither to move nor to produce their own feeding current, for they live in flowing water. The larvae of buffalo-gnats attach themselves by suckers to sticks and stones in rapid streams (some species thrive in waterfalls), and stick their heads up into the water; two fans of bristles on the mouth-parts form strainers which trap solid particles in the water and pass them to the mouth. A few caddis-fly larvae, which do not have the usual cases, live in less swiftly running water. They spread a net, made from silk like a spider's web, across the current between stones or other supports. Then all they have to do is to collect the small animals and other food-particles which accumulate in the net.



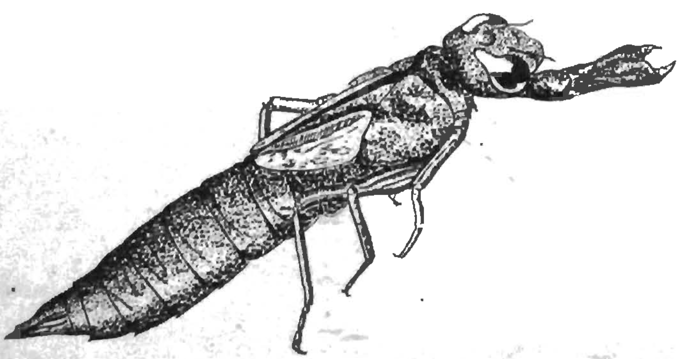
Green Hydra, on the left-hand retracted, on the right with tentacles extended as when feeding

The freshwater polyp (*Hydra*) resembles some filter-feeders in that it stays in one place and waits for its food to come along. But its food is rather different, consisting of actively swimming animals such as water-fleas. It is described as 'predacious' because it has to make active movements with its tentacles to catch and subdue its prey. There is an unusual flowering plant called bladderwort which is closely comparable. Unlike the majority of plants, it feeds on water-fleas and other small animals; these are trapped in certain leaves which are modified into bladders like miniature lobster-pots. The unsuspecting water-fleas swim into these bladders and are unable to escape.

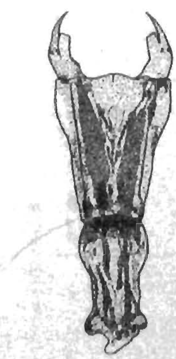
No account of feeding habits would be complete without reference to those voracious gluttons the larger dytiscid water-beetles and more particularly their larvae. The adult *Dytiscus* has very thick and strong jaws which enable it to attack even small fish. The larva has thinner and very sharp-pointed ones which are not designed for crushing but rather for piercing; each mandible contains a tube opening by a perforation at the tip, through which the juices of the prey are sucked into the angles of the mouth cavity, the real mouth opening being closed and useless so that no solid food can be taken in. If you keep several dytiscid larvae together in a small vessel of water, it will not be long before you find one or more of them dead and shrunken, drained of its contents by one of its brethren.

Dragonfly nymphs have a special development of one of the mouth-parts to form a long 'mask'. This has a pair of pincers at its tip, generally armed with spines, with which the prey is caught. It has an elbow joint enabling it to be shot out with lightning speed, and then pulled back to bring the prey to the mouth where the jaws get to work on it.

The water-scorpion (*Nepa*) and water stick-



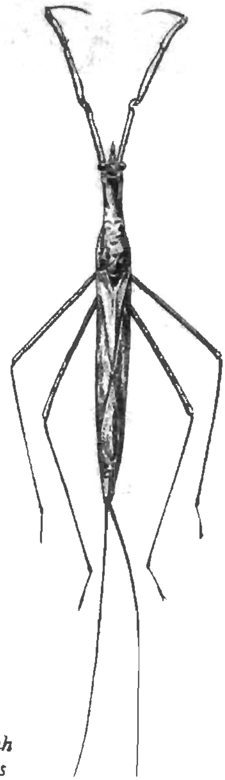
Dragonfly nymph with the mask extended to catch prey



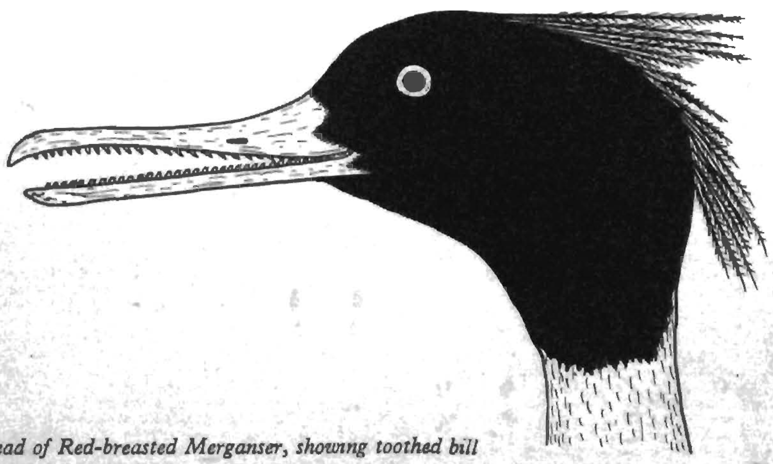
'Mask' of the nymph of a dragonfly (Aeshna), *magnified*

insect (*Ranatra*) have front legs with two of the segments hinged and fitting each other like the blade and handle of a pocket knife. A more effective method for catching and holding prey can hardly be imagined.

Among vertebrate animals, the duck family makes an interesting study in degrees of adaptation to aquatic feeding. The extraordinary and ungainly 'up-ending' of a swan or a domestic duck in a lake or pond is a special habit which enables a once terrestrial creature to feed under water. It is collecting mainly vegetable food, although a few snails and insect larvae do not come amiss. Diving ducks, such as Pochard and Tufted Duck, like grebes, can submerge entirely and swim under the surface, and so collect vegetation from deeper water; but some (especially grebes) take a much higher proportion of animal food. The 'saw-bill' ducks (the Goosander and Merganser) have gone over entirely to animal food and eat chiefly fish. The series of sharp, backwardly-directed teeth on their bills are admirably suited to catching and holding such a slippery animal.



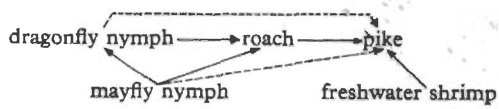
Water Stick-insect which has prehensile front legs



Head of Red-breasted Merganser, showing toothed bill

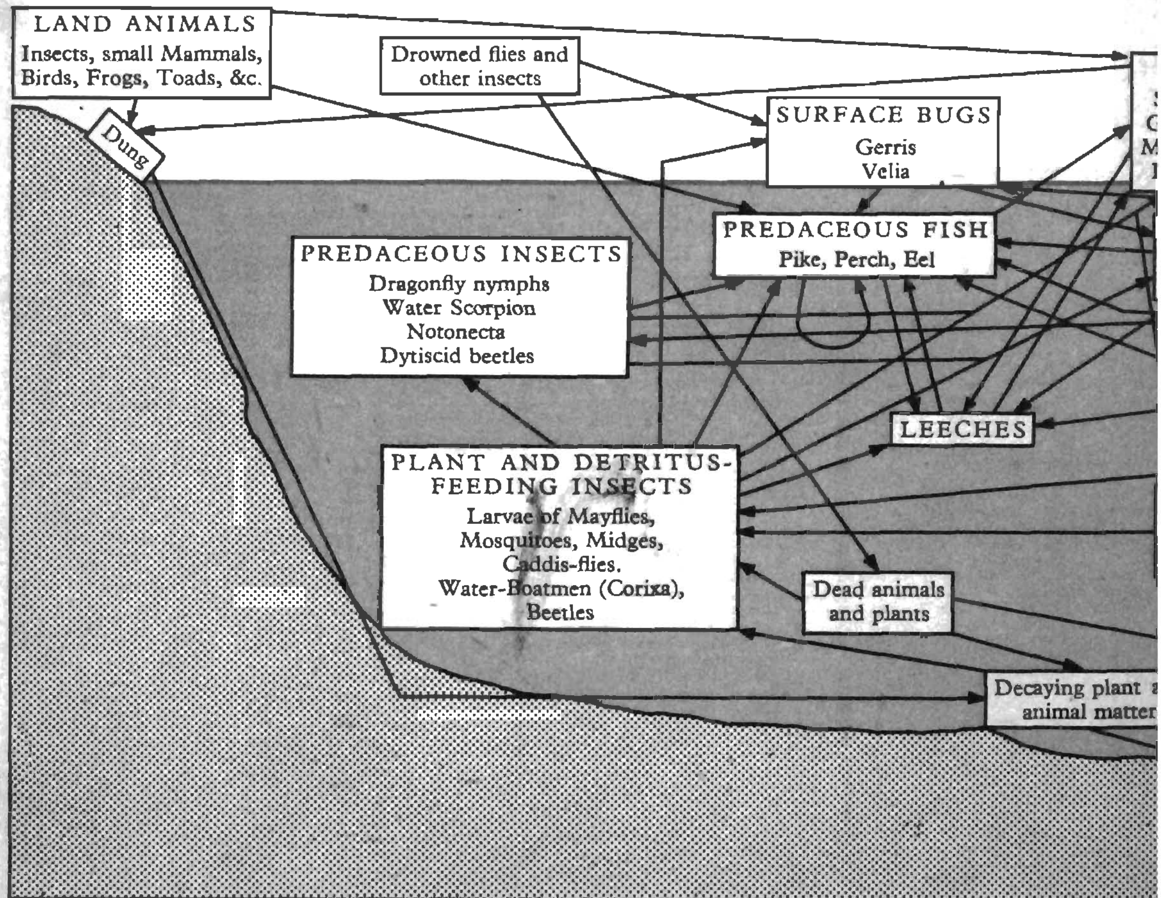
FOOD CHAINS

An intriguing aspect of the food problem is the influence which species of different feeding habits have upon one another. Under natural conditions, we find that species *A* preys upon species *B*, species *B* upon species *C*, and so on, forming chains in which one link influences directly or indirectly all the others above and below it. For instance, pike prey chiefly upon fish such as roach, and roach upon insects such as dragonfly and mayfly nymphs, the last two being further involved because the former preys upon the latter. This simple little system is made more complicated by the fact that pike also occasionally eat freshwater shrimps and insects such as those lower in the food-chain. We can represent these relationships on paper in the following manner:



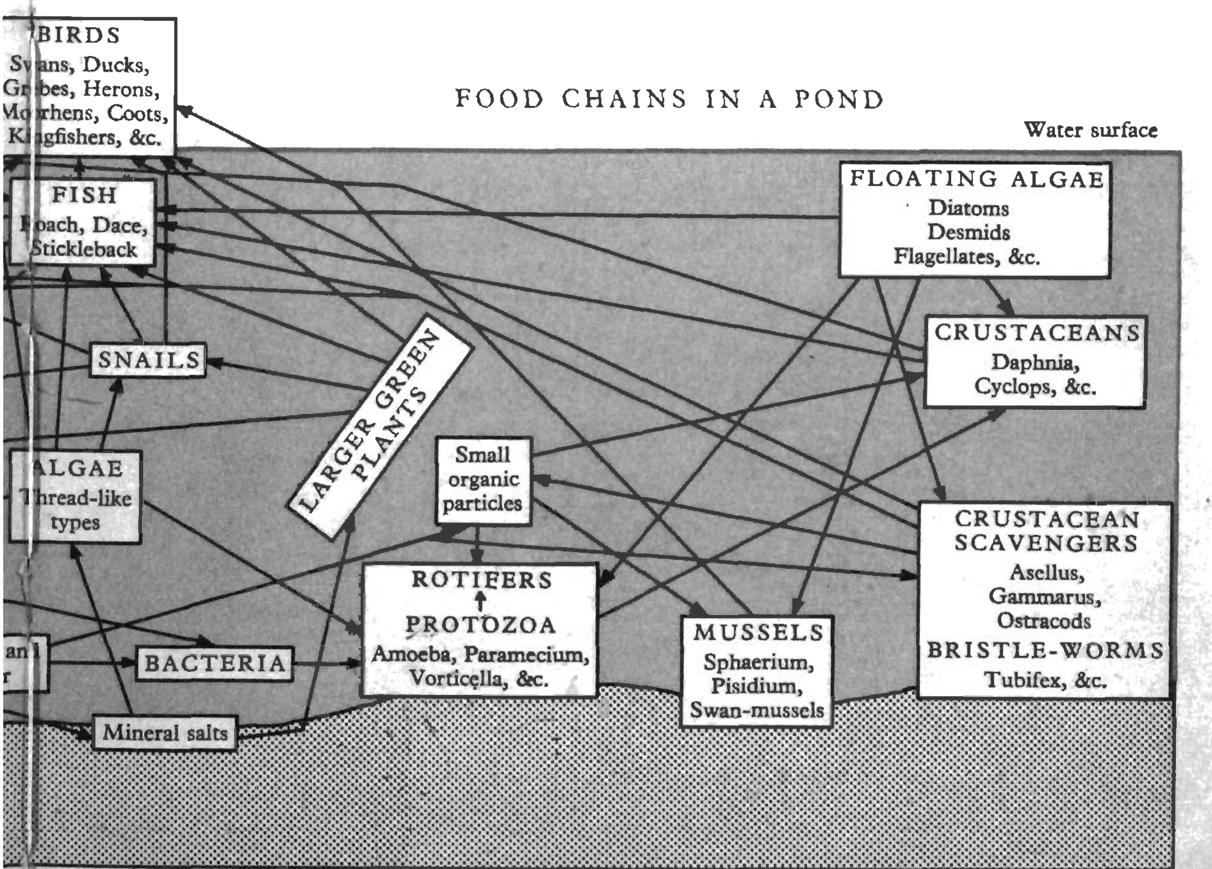
Dotted lines are used for the less usual feeding habits.

It is of great value to be able to draw up a diagram in this way, because one can make important predictions from it. One could suggest with some confidence, for instance, that if



pike were absent roach would increase, with a corresponding decrease in the insects; if the roach decreased, then the pike would suffer correspondingly, but might get a living by more than the usual attention to shrimps and insects. Actually few food chains in nature are as simple as this, for the situation is complicated by the presence and influence of all manner of other species; among these, plants play their part as well as animals, for they usually form the starting link in a chain. The diagram indicates the food relationships of many of the more familiar living (and a few non-living) things in a pond. It really consists of a number of different food chains interacting together in a complex 'web of life'. Species or groups of species are placed in the diagram as far as possible in the parts of the pond which they usually inhabit. Try to work out the various repercussions which would result after the removal from the pond of any one species or group of species with similar feeding habits, and you will realize what a complicated thing a natural community of living organisms is. This diagram is nothing like complete, for a typical pond community may contain many hundreds of kinds of animals and plants, to say nothing of myriads of bacteria. And while it shows species grouped together as 'scavengers', 'snails', and so on, each such group really comprises a number of species, each one differing to a greater or lesser extent from all the others in its feeding habits and influence on the community as a whole.

FOOD CHAINS IN A POND

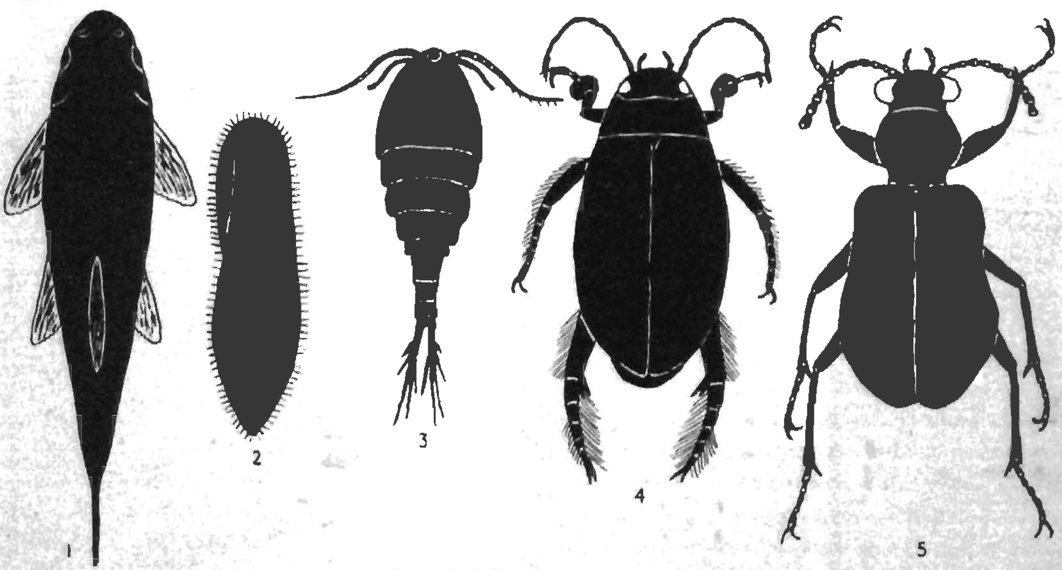


MOVEMENT IN WATER

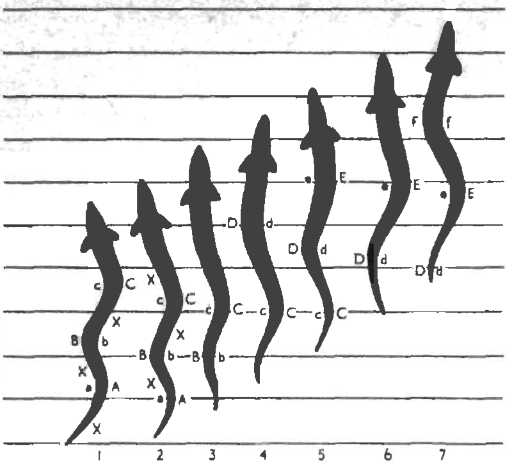
SWIMMING in water is a very different matter from moving about on dry land. In one way an aquatic animal has an advantage, because it lives in a liquid about as heavy as itself, so that it has to make no serious effort to avoid sinking. Land animals, since they live in air, are not buoyed up in the same way, and have to raise and support their bodies off the ground before they can move about (there are, of course, exceptions such as snakes). The limbs which the animal uses for movement are also involved in supporting the body, whereas aquatic animals can devote all the efforts of their limbs to moving.

The much greater resistance to progress offered by water as compared with air, on the other hand, puts aquatic animals at a disadvantage. A well streamlined shape is essential for a body to move in water at all swiftly. Some of the animals which swim fastest in relation to their size, such as those illustrated in silhouette, have certain similarities of shape. Their outline is evenly rounded along the sides and free from irregularities, for these would create resistance and act as a brake. If the aquatic forms have relatives living on land, such as beetles, the latter show no such adaptation of shape, for it would be of no advantage to them. The front end of the aquatic forms tends to be bluntly rounded and the hind end tapered to a point. One might think that this was the wrong way round, and that the pointed end should go first for best results, but this is not so. The reasons have been investigated carefully in designing the fusilage and wings of modern high-speed aircraft, for here even the resistance of the air becomes important. Recent experience has only just taught man what nature discovered millions of years ago.

Just as a land animal has to push backwards against the ground or a bird against the air to drive its body forwards, so an aquatic animal

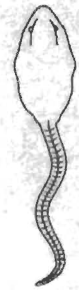


The shapes of some fast-swimming aquatic animals and one land animal (not drawn to scale)
1. *Fish (Roach) from above.* 2. *Protozoon* (Paramecium). 3. *Crustacean* (Cyclops). 4. *Water-beetle* (Dytiscus) 5. *Land-beetle* (Elaphrus). *Notice the streamlined shape of the aquatic animals compared with the land-beetle*



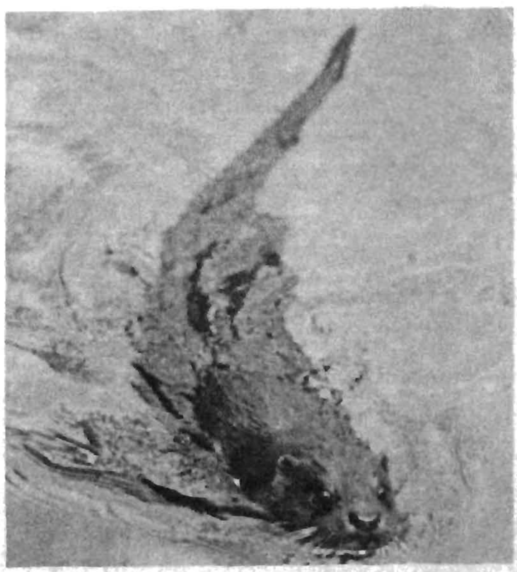
Successive positions of the same eel during swimming. The parallel lines show the progress of the fish. a, b, c, *and so on are successive waves of contraction and* A, B, C, *and so on are the convex bulges formed opposite them.* X *indicates surfaces which move backwards with the contraction wave, pushing on the water and driving the fish forward*

has to push against the water, and there are many ways in which it may do this. Consider the swimming of a fish: it does not swim, as is commonly supposed, by lashing its tail from side to side, for this would only turn the fish's head first to one side and then to the other (just as moving the rudder turns a rowing boat), and progress through the water would be negligible. A glimpse of a trout as it darts off at lightning speed on one's approach leaves no doubt that more effective forces are at work. They involve not the fins, but the muscles running down the body, which are arranged in a series of blocks down each side of the backbone (the flakes which are so obvious when eating cod or haddock). Their contraction spreads in a wave from front to rear, first a wave passing down one side of the body, then one down the other. Contraction causes a shortening of the body on that side, producing a concave bend (with a corresponding convex bulge on the opposite side) which passes backwards with the contraction wave; the next contraction wave is on the opposite side, and produces a bend in the opposite direction. In a long, thin fish like an eel there will be several waves passing down the body at any one moment, originating in the order *a* to *f* (see diagram). They throw the body into a series of S-shaped curves. In between the curves there will be a series of surfaces (some of which are marked *X*) which are directed backwards and outwards, and which pass backwards as the contraction waves proceed, thus pressing backwards against the water and pushing the fish forwards.



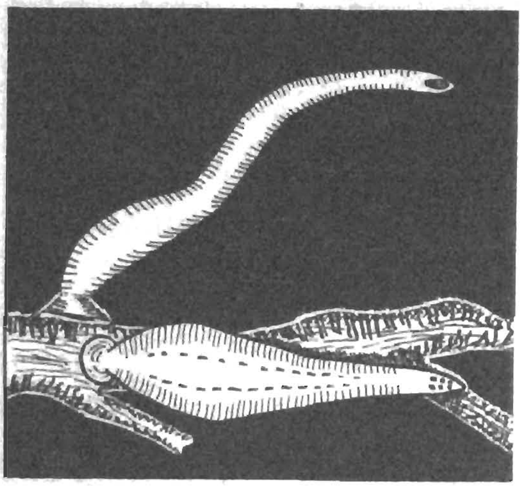
Tadpole swimming. Notice the s-shaped curves in the tail

These contraction waves are difficult to make out in a short, thick fish like a roach or perch, but can be detected by high-speed photography. They can be seen easily in an eel or a tadpole's tail. The otter, on the other hand, although it has a somewhat similar tail, broadened at the base and gently tapering towards the tip, uses it only as a rudder, the driving force being provided by the webbed feet.



A. R. Thompson

Otter swimming, using its tail as a rudder

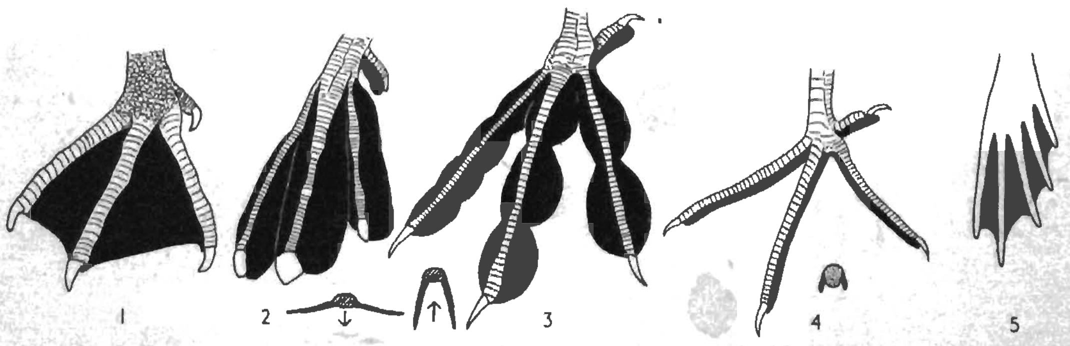


Leeches. Above, Haemopis (*Horse Leech*); below, Glossiphonia

The fish's method of propulsion is characteristic of vertebrate animals, but is so effective that it is not surprising to find that it has been acquired independently by some of the simpler animals which have taken secondarily to the water; in most such cases the flattening of the body, which improves the effect, is up and down (that is, the body appears broadest seen from above or below), while in a typical fish it is from side to side; the curvature resulting from the contraction waves naturally follows the same direction. Leeches will occasionally release their hold on the weeds or other objects on which they normally move, and by a series of contraction waves swim through the water at great speed—a most impressive performance. Nymphs of some mayflies can swim very fast by similar contraction waves in the hind part of the body.

One might imagine that a fish could swim with its paired fins, using them as oars, but they are in fact only used for minor vertical movements, and for maintaining stability. There are, however, other aquatic animals which do use oars in some form for locomotion. For even movement, the effective stroke of an oar must be always in one direction. During the recovery stroke, when it is moved back into its original position in preparation for another effective stroke, it must offer a minimum of resistance to the water. An oar used in a rowing boat is of course lifted out of the water during the recovery stroke to avoid resistance. In animals, however, if they are not to be confined to the surface of the water, the appendages which serve as oars have to remain under water throughout both the effective and the recovery strokes, and must be constructed so as to minimize resistance during the latter.

In water-fowl the oar takes the form of a webbed foot; in ducks, geese, and swans the web is continuous across all three front toes, and is folded up during the recovery stroke by flexing the toes and drawing them all up together. In grebes, the Coot, and to a lesser extent the Moorhen, each toe has a strip of web

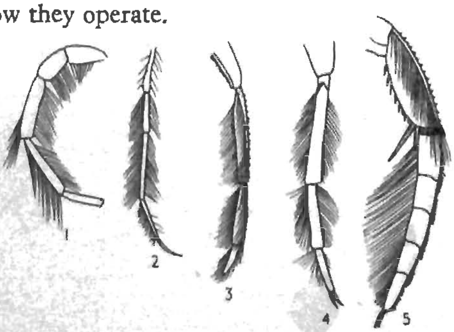


Webbed feet. 1. *Pink-footed Goose.* 2. *Great Crested Grebe.* 3. *Coot.* 4. *Moorhen.* 5. *Frog. Diagrams of toes show the position of the membranes during the forward and back strokes*

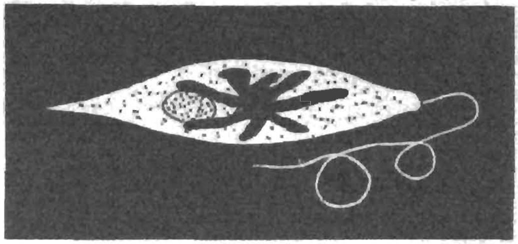
down both sides, but it is not continuous from one toe to the next; on the back (effective) stroke the lobes spread and offer maximum resistance, while on the recovery stroke they close up like a book and are drawn passively through the water. The frog has hind feet webbed like a duck's, and they operate in the same way; its relatives, the newts, have no need of such a well-developed web, since they have flexible bodies with long, muscular tails and can swim like fish.

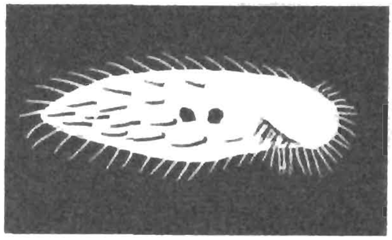
In another form of oar structure, the appendages have a fringe of fine hairs along each side, which spread out on the back-stroke to give the necessary resistance, but are dragged passively through the water as the limb is moved forwards. The water-boatmen are excellent examples of this method and can move at great speed. In common with adult dytiscid water-beetles, they have only the hind legs feathered in this way, but some water-beetle larvae have all three pairs of legs fringed. Caddis-fly larvae usually crawl, but *Triaenodes* has the hind pair of legs hair-fringed, and when swimming extends these forwards and out of the mouth of the beautifully constructed case, which is dragged slowly through the water.

Some of the smaller crustacea, such as the water-fleas and copepods, use their antennae as oars, and with great effect, although they are not fringed with hairs. They are so small, however, and move so fast that it is difficult to see just how they operate.

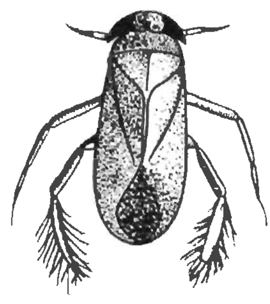


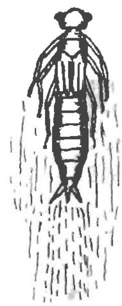
Legs with swimming hairs. 1. *Water-mite.* 2. *Caddis-fly larva.* 3. *Backswimmer* (Notonecta). 4, 5. *Larva and adult of* Dytiscus *beetle*

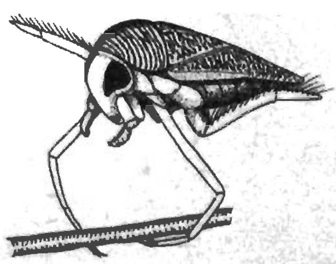

A protozoon (Euglena) *with a flagellum, greatly magnified*


A protozoon (Oxytricha) *with cilia, greatly magnified*


Triaenodes, *a swimming caddis-fly larva*


Corixa, *a water-boatman with swimming hairs on its hind legs*


Nymph of dragonfly (Aeshna) *swimming by 'jet-propulsion'*


Water-boatman (Corixa). *The front legs are specialized for feeding, the middle legs for anchoring, and the hind legs have hairs for swimming*

Some species of dytiscid beetle larvae have swimming hairs on the sides of the hind end of the body. These are used in the same way as those on the legs, but usually only when a sudden turn of speed is required. The larva holds the tip of the abdomen bent upwards as it breathes at the surface (p. 17), and by rapidly forcing it backwards and downwards the hair-fringes are made to splay out and press on the water. In the curious larva of the beetle *Acilius*, which unlike others spends most of its time cruising slowly in mid-water, this action is startlingly effective as a means of escaping, for it can put several inches between itself and an enemy in the twinkling of an eye.

Distinct from these swimming hairs found in insects are the much smaller and more numerous cilia, which clothe part or all of the bodies of a great many of the very small animals, including some of the protozoa, and the smaller many-celled animals, such as rotifers. The cilia move actively like microscopic oars, being held straight and stiff during the back-stroke, and bending over to reduce resistance as they are swung forwards passively during the recovery stroke. In spite of their number and minute size, they are controlled individually and systematically. Waves of action pass through the forest of cilia, resembling the waves of movement which pass over a field of corn with successive gusts of wind.

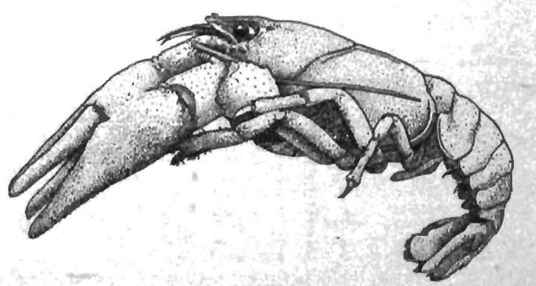
Some small organisms, the flagellate protozoa, have one or two long, whip-like threads called 'flagella' with which they propel themselves.

Planarian worms and snails use cilia not for swimming but for crawling over a track of slime which they lay as they glide over solid objects. The action is similar, however, in that the cilia beat actively backwards in the slime, propelling the animal smoothly forwards; they are then drawn passively forwards again in preparation for the next backward stroke.

Mussels move exceedingly slowly through the bottom mud, using the foot, which is extended and thrust below the earth and there fixed by inflating it through blood-pressure, while the body and shell are drawn forwards on to it by muscular contraction. The whole performance is then slowly and doggedly repeated.

All these are standard methods of locomotion, found widely in aquatic animals, or characteristic of particular groups. Some other methods which are associated with special types of habitat, such as the surface film, will be described elsewhere. It remains to mention one or two peculiar types of movement which have been developed as side-lines of evolution by some of the secondarily aquatic animals.

The principle of jet-propulsion, like the best designs in streamlining, was first exploited by animals, such as the nymphs of the larger dragonflies, long before it was used by engineers. In the hind end of the gut these nymphs have a rectal gill which is used for moving as well as for breathing; by taking water slowly into the rectum and then expelling it violently to the rear, the animal is driven forwards at some speed. This is a very valuable supplementary method of progress to replace the normal slow crawl, and can be used as an escape mechanism, as the animal can, with a sudden turn of speed, rapidly remove itself from danger to a safe distance. The curious action of *Acilius* larvae, already described, is another example. The crayfish, which normally crawls slowly over the bottom, can dart off quickly in reverse, by fanning out its tail-fin and bending the abdomen violently downwards under the body, so that the fin is driven forwards and propels the animal



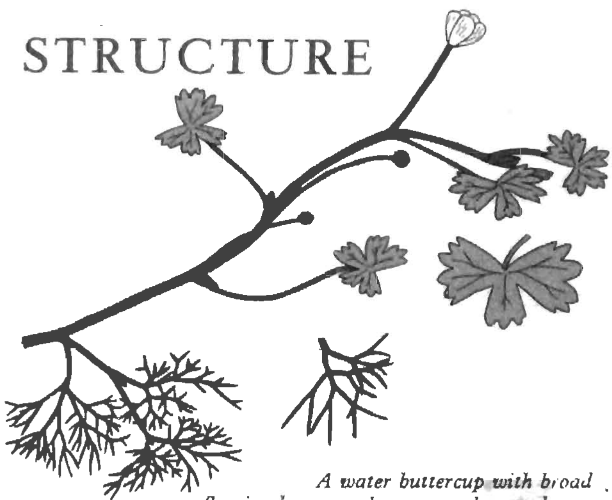
Crayfish in position adopted when swimming backwards

backwards. *Simulium* larvae (p. 48) and phantom larvae (p. 43) have other forms of escape mechanism.

Since a land animal, to move about efficiently, requires supporting above the solid earth, the body must always be the same way up, with the legs underneath. An aquatic animal is in no such need of support, and it matters little to it which way up it lives. Some crustaceans, such as the freshwater shrimp, live and swim on their sides; another crustacean, the fairy shrimp, swims upside down, legs upwards, and the same is true of the water-boatmen *Notonecta* and *Plea*.

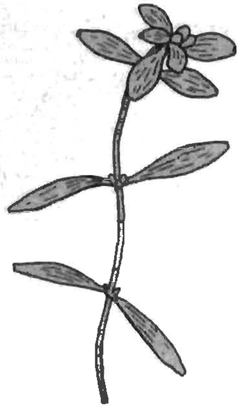
As with breathing habits, some of the invaders from the land have done little or nothing to change a terrestrial method of locomotion for one more suited to water; stonefly nymphs crawl over the bottom and the vegetation like any land insect, and so do many of the hydrophilid water-beetles. Most adult insects (water-beetles, water-boatmen, and pond-skaters) have retained the power of flight, which is of great value in enabling them to migrate from one pond to another; some other small animals, such as *Vorticella* and water-mites, attach themselves to the bodies of these migrating insects and travel with them.

THE FORM AND STRUCTURE OF WATER PLANTS



A water buttercup with broad floating leaves and narrow submerged ones

PLANTS which grow wholly or partly under water show some general differences from land plants. Let us first consider the shape of the leaves. Instead of the usual narrow stalk and broad, flat leaf-blade of the land plant, submerged leaves are often narrow and strap-like. Sometimes they are intricately dissected into thin threads, as in the water buttercup. Plants which grow partly submerged but reach the water surface at their extremities have other peculiarities. Some kinds of water buttercup, for example, often have leaves of two kinds, submerged and floating types, the latter with broad, often rounded, leaf-blades which float flattened out on the surface. Other plants, as well as typical submerged leaves, have leaves which stick up above the surface, like the leaves of ordinary land plants. Arrowhead has all three types, submerged, floating, and emergent, but they are not all found on the same plant at the same time. Different types of leaf are found in land plants also, but here there is usually a gradual change-over from one type to another from the bottom to the top of the stem. In water plants there are often clear-cut differences, which one is tempted to explain as features adapted to their environment. Submerged

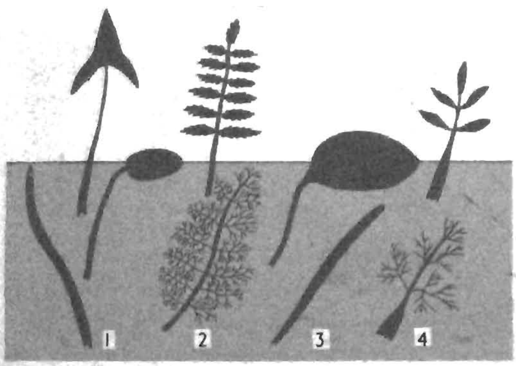


Water Starwort. The shape of the upper (floating) and lower leaves differ slightly

leaves may encounter severe buffeting from water currents and wave action, which would tear broad leaf-blades to shreds, but have much less effect on narrow and more pliant leaves which offer less resistance. The broad, floating leaves, on the other hand, are well suited both to buoy up the plant and to obtain a generous share of the sun's rays which are so vital to plant life.

The causes of such remarkable leaf differences on one and the same plant are far from clear. It has been suggested that changes in the amount of food substances available during the period when the plant is producing leaves may be the cause, so that there is a change-over from one leaf-type to another. Although this may be true in some cases, there is evidence that in others each leaf develops this or that shape in direct response to the conditions under which it grows, such as the rate of flow of the water.

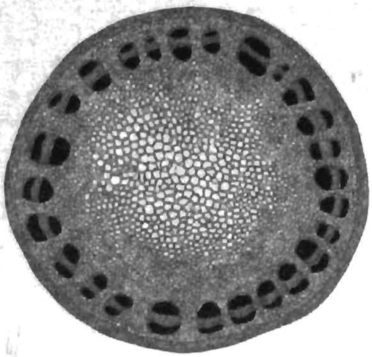
Floating leaves have another peculiarity. The stomata, that is, the microscopic openings on a plant's surface through which gases are exchanged between its tissues and the air, are mostly on the under surface of the leaves of land plants; but in floating leaves, they must be on the upper surface in order to make contact with the air possible. This can be shown if a water-lily leaf is collected carefully, without damaging it, and the leaf-blade submerged in a large bowl of water; on blowing hard through the cut end of the stalk small bubbles will usually escape through the stomata on the upper surface.



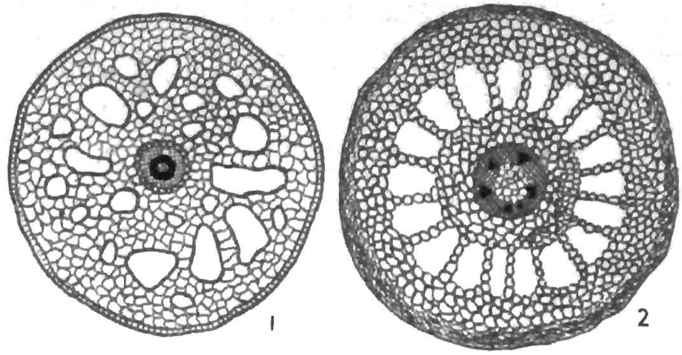
Water plants showing difference between leaves above water, floating leaves at surface, and submerged leaves. 1. *Arrowhead.* 2. *Water Parsnip.* 3. *Floating Pondweed.* 4. *Lesser Marshwort*

Water Milfoil with finely divided leaves

One very widespread feature of aquatic flowering plants concerns the inner structure of the stem. Most land plants have stems strong enough to enable them to stand erect. This demands a framework or skeleton of some strong material, largely wood; the trunks of



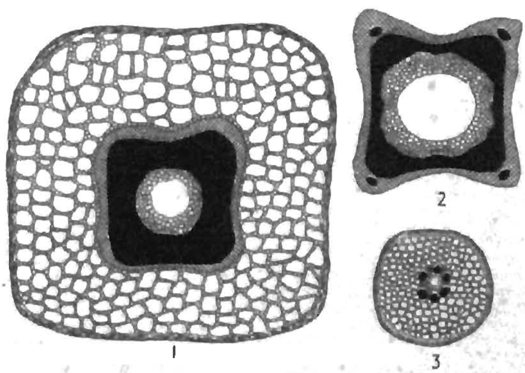
Section through the stem of a land plant (Sunflower). The woody tissues are shown in black



Sections through stems of (1) Water Violet and (2) Water Milfoil showing the small amount of woody tissue in a central position, and the air-filled spaces in the tissues

trees consist mainly of wood, but even soft-stemmed plants have some woody substance. How much of this substance, called 'lignin', a stem contains can easily be shown by staining. If you cut very thin slices transversely through the stem of a sunflower or other similar land plant, and treat them on a glass slide first with a drop of phloroglucin and then with one of concentrated hydrochloric acid, after a minute or two the lignin will show up, coloured a beautiful magenta pink. It will be found to be in separate strands arranged in a cylinder round the outside, just like the steel rods in a reinforced concrete pillar. This arrangement gives the stem enough rigidity to hold it erect. If the stem of some underwater plant, such as water milfoil, is treated similarly, it will be found that the woody skeleton is far less extensive, and in most cases is concentrated into the centre of the stem. This arrangement gives less rigidity to a stem which in any case is buoyed up by the water. It does, however, give the stem tensile strength to withstand the pull due to water currents and wave action. One has only to watch plant stems being washed about in the current of a rapidly flowing river to realize how important this is.

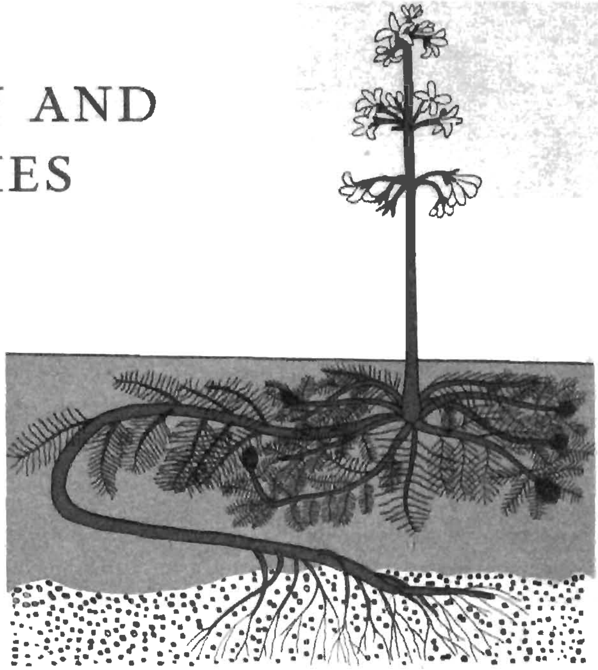
Outside the woody cylinder (and sometimes inside it as well) many water plants have a kind of tissue with many air-spaces in it. The cells of the plant are restricted to the network of partitions between the spaces. This 'air-tissue' is peculiar to water plants and adapted to their respiratory problems. Land plants are always surrounded by a plentiful supply of oxygen, but submerged plants, which have to get their oxygen from the water where the supply is meagre and variable, accumulate and maintain a reservoir or 'internal atmosphere' in the air-spaces. These air-spaces are in direct contact with the cells requiring the oxygen. As with leaf-shape, this tissue is often acquired in response to the environment: in the gipsywort, for example, a submerged stem develops air-tissue, while one grown in air has the structure found in ordinary land plants.



Sections of stems of Gipsywort

1. Submerged stem. 2. Aerial stem. 3. Submerged creeping stem or runner. Woody tissues shown in black

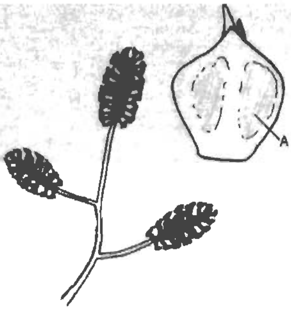
REPRODUCTION AND LIFE-HISTORIES



Water Violet with rosette of leaves forming platform to support flowers

FLOWERING plants of the dry land reproduce their kind by a process in which 'pollination' of the flower plays a part. Very small bodies called pollen-grains are transferred from the stamens of one flower to the stigma of another (except in the less common instances of self-pollination, where the pollen is transferred to the stigma of the same flower). This process is followed by the fertilization of the egg-cells and later on by the formation of the seeds. The transference of pollen is brought about usually either by the wind, or by insects which visit the flowers to get nectar. Neither method could be effective under water, for there is no wind, and nectar would dissolve in the water; also, the pollen would get washed off insects if they carried it. And so it is not surprising that those flowering plants which have left the land for the water are often found to have developed some special device connected with pollination. In many, the reproductive organs are found in the parts above water, thus betraying their land origin. The marsh and swamp plants have much of their stems and all their flowers out of water, and are wind- or insect-pollinated. Many of the more strictly aquatic forms even, with their foliage largely or entirely submerged, contrive to raise their flowers above the surface. The large broad leaves of some, such as the floating pondweed and the rather similar *Polygonum amphibium*, form a floating platform to support the flower stalk. In others, such as the water violet and one kind of water milfoil, a spreading rosette of thread-like leaves, only just below the surface, gives the necessary support. In some, such as the frogbit and water-lily, the flowers are insect-pollinated, and in others, such as the floating pondweed, they are wind-pollinated. In other plants water itself plays a part in pollination. The Canadian pondweed has flowers of two kinds: male or pollen-producing ones, which are completely submerged, and female ones, in which the stigma is carried up just to the surface by the growth of a long, slender flower tube

Polygonum amphibium *with flower stem supported by floating leaves*



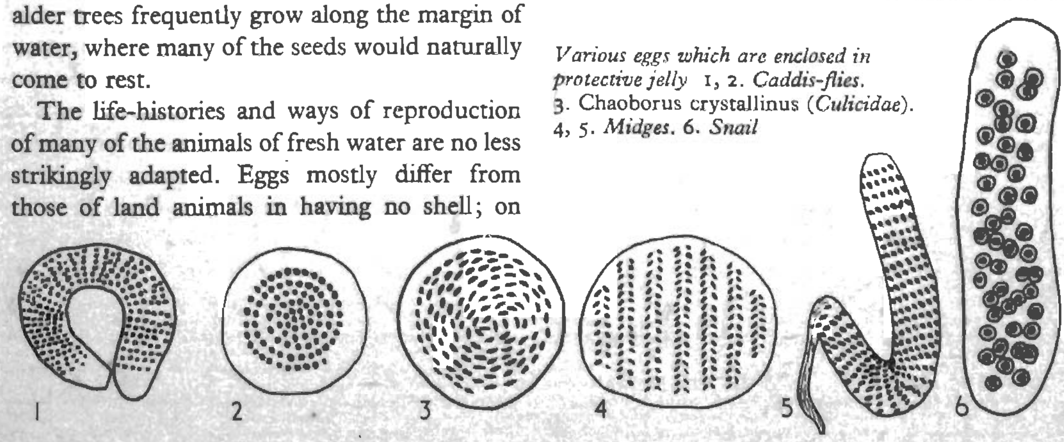
Cones and floating fruit (much enlarged) of alder. A. *Air-space*

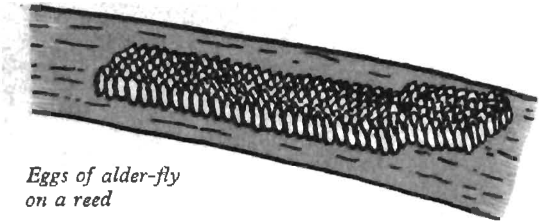
which may reach a length of 30 centimetres; the male flowers break away and float up to the surface, where flowers or free pollen float about or get blown over the surface by the wind, and may pollinate the stigma of a female flower. The male and female flowers of hornwort are both entirely submerged and the pollen grains are washed under water from one to the other. Thus a fairly complete series can be found to bridge the gap between the thoroughly terrestrial, insect- or wind-pollinated plant on the one hand, and the sub-aquatic, completely water-pollinated plant on the other.

The seeds of land plants are distributed by wind (as in the thistle) or by animals (as in the clinging burdock), much as the pollen grains are carried about by wind or insects. A number of waterside and aquatic plants make use of water for this purpose, producing fruits or seeds which readily float, and may be carried to some spot suitable for their germination and growth. The fruits of the alder fall from last year's cone-like catkins hanging on the tree, and float on water for an unlimited period owing to air-spaces within their tissues. This explains why alder trees frequently grow along the margin of water, where many of the seeds would naturally come to rest.

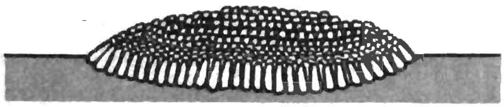
The life-histories and ways of reproduction of many of the animals of fresh water are no less strikingly adapted. Eggs mostly differ from those of land animals in having no shell; on land a shell is necessary to prevent an egg drying up. Aquatic eggs may be protected from attack, however, by some device or other. Many are set in a jelly or spawn, familiar instances being those of the frog and toad, which have to lay their eggs in water because they are fertilized externally like those of fish. The eggs are laid with a thin coat of jelly on the outside which absorbs water and swells up to many times its original volume. The same device on a smaller scale is employed by water-snails, some kinds of caddis-flies, water-mites, many midges, and the gnat *Chaoborus*. In a midge (*Chironomus dorsalis*) the eggs are arranged in a string which makes a series of circles round a long, sausage-shaped mass of jelly. The alder-fly lays eggs in large batches on overhanging vegetation, so that on hatching the young larvae fall straight into the water. Gnats lay a number of eggs in a raft which floats on the water surface. These rafts are remarkably well constructed; the eggs are long and tapered at one end, and glued together side by side with their thicker ends downwards. This gives the raft as a whole a suitable boat-shaped curve, with the edges turned up; if it is placed upside down on the water it will immediately right itself. This is because the thick ends of the eggs are readily wetted, while the thin ends repel water and resist being wetted; the raft therefore tends to come to rest with the thick ends of the eggs downwards, in contact with the water. This is

Various eggs which are enclosed in protective jelly 1, 2. *Caddis-flies.* 3. Chaoborus crystallinus (*Culicidae*). 4, 5. *Midges.* 6. *Snail*

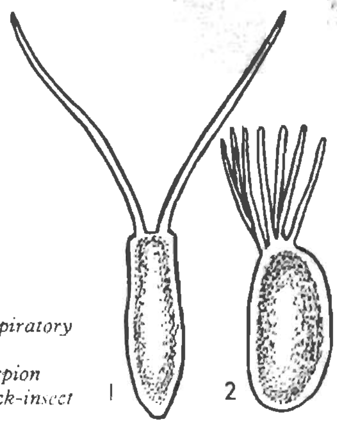




Eggs of alder-fly on a reed



Egg raft of gnat (Culex)



Eggs with respiratory filaments
1. Water-scorpion
2. Water Stick-insect

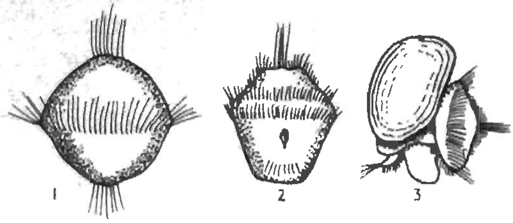
important to the young larvae because they emerge from the thick ends of the eggs and thus find themselves in the water instead of being stranded on top of the raft.

Many beetles, and a few other insects like *Notonecta*, have piercing 'ovipositors' (a female insect's egg-laying apparatus) with which they insert eggs into the stems of plants. Here they are protected and can get oxygen for respiration from the air-spaces in the stem. The eggs of the water stick-insect have two horn-like, hollow filaments which may sometimes protrude through a floating leaf or stem up into the air, anchoring the egg and assisting in respiration. The eggs of the water-scorpion have six to eight such filaments, which protrude from the dead plants in which the eggs are usually fixed.

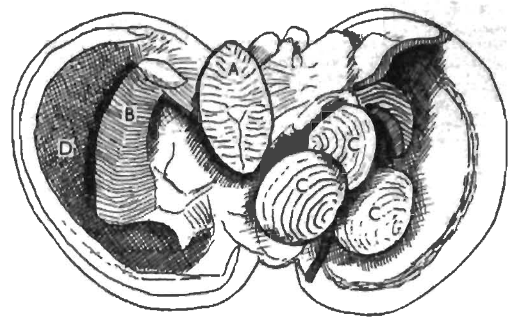
Dragonflies lay their eggs in many ways. Some merely shed them on to the water as they fly over it. Others glide down to the surface and wipe the eggs off the tip of the abdomen by dipping it under water while on the wing (a method used also by certain mayflies). Others again settle on plant stems protruding above the surface, and insert the eggs into the tissues with a piercing ovipositor. In some cases the female climbs right down under the surface of the water to do this; the male holds her by the neck with a pair of 'claspers' at the tip of his abdomen and when she has finished drags her out.

A great many plants, and most sedentary or slow-moving animals, are distributed or scattered at some point in their life-history. This is of great importance for the survival and success of the species, since it enables it to spread widely and thus be more likely to find localities favourable to it. Free-swimming larval stages of many of the molluscs, worms, and other animals living in the sea form part of the plankton and float about at the mercy of the current. In fresh water such stages would often be a serious danger, because sooner or later the water might carry them to the sea. Very few living things can survive a change from fresh to salt water, and in any case they would later have to return upstream to their natural home. Freshwater animals belonging to groups which are found mainly in the sea do not have free-swimming larvae therefore, even though members of the group normally have them.

The larva of marine molluscs has a girdle of cilia and drifts about at the surface of the sea. The swan mussel, a freshwater mollusc, has lost this stage; the embryo remains longer in the parent shell until a curious type of larva is produced, which has two hinged and toothed valves. After release from its mother's shell this larva lies on the bottom; it can open and close its valves, and if it is to continue its life-history it must make contact with a fish, to which it adheres by a sticky 'byssus' thread. The valves are then closed sharply and the



Planktonic marine larvae with cilia. 1. *Larva of annelid worm.* 2, 3. *Larvae of mollusc at different stages*



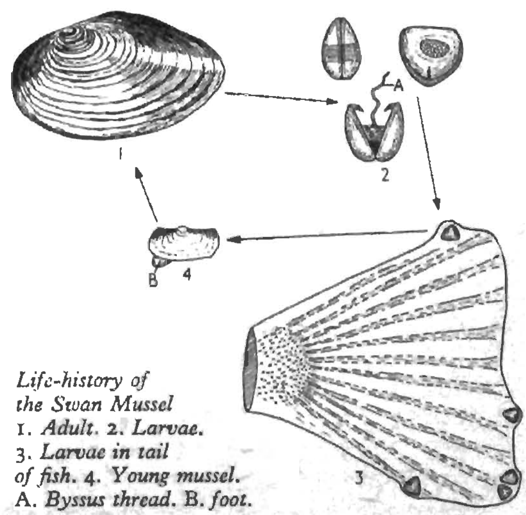
A viviparous mollusc (Pisidium) *with shell opened and mantle cut away on one side to show fully formed young.* A. *Foot.* B. *Gill.* C. *Young.* D. *Mantle*

teeth become embedded in the skin of the fish. For about three months the larva then lives as a parasite in the fish's skin, from which it absorbs food. By the end of this time a new shell has formed beneath the valves and the young mussel, now a small replica of the adult, escapes from the fish and immediately burrows in the mud. This completes a curious life-history in which the swan mussel not only avoids the dangers of a free-swimming stage, but also achieves dispersal through the travels of the fish. The heavy odds against it completing such a complicated life-cycle are offset by the enormous number of larvae produced by each mussel.

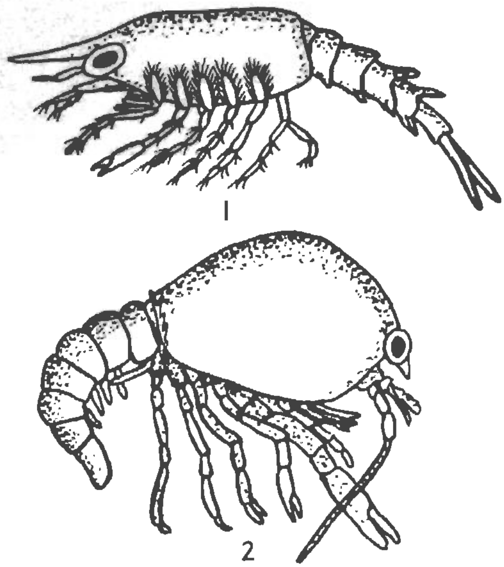
A very much smaller mussel, *Pisidium*, has lost the larval stages altogether, and become 'viviparous', which means that it produces well-developed, active young exactly like the parent except in size.

The nearest marine relative of the crayfish is the lobster. This has a larval stage which swims at the surface of the sea with flattened, hair-fringed expansions of the legs. There is no such stage in the crayfish; when laid, the eggs become attached to the swimmerets on the abdomen of the female, and produce larvae which are almost identical in structure with the adults, and continue to hang on to their mother's appendages until ready to crawl about on the bottom and fend for themselves.

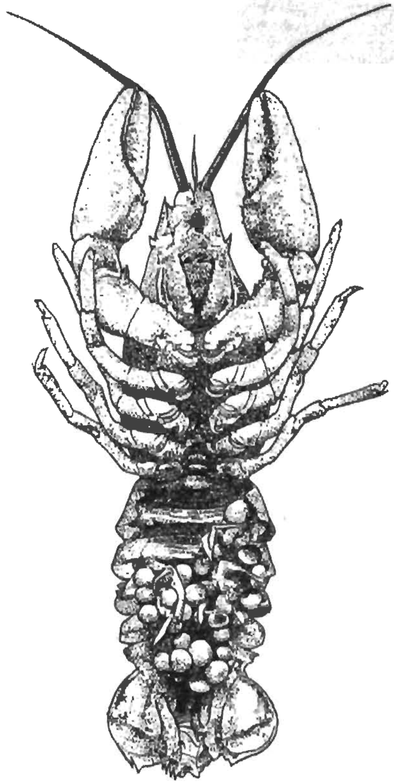
Many insects are faced with a difficult problem when it is time for the adults to emerge. Often the nymphal or pupal stage is aquatic, while the adult is a delicate aerial creature with wings which might suffer damage if it emerged directly into the water. This difficulty is overcome in various ways. In dragonflies and stoneflies the nymphs crawl out of the water up plant stems or other objects and the adults emerge in the air. Mayflies have an additional 'subimago' stage which emerges from the nymph and flies away; it resembles the adult, but has a thin external skin which possibly acts as a protection during emergence, and is shed later. In many flies, such as gnats and midges, the pupa rises to the surface when the adult is ready to emerge, and a split appears in the skin along the top of the thorax; this split opens directly into the air and the fly emerges dry; the spreading and



Life-history of the Swan Mussel 1. *Adult.* 2. *Larvae.* 3. *Larvae in tail of fish.* 4. *Young mussel.* A. *Byssus thread.* B. *foot.*



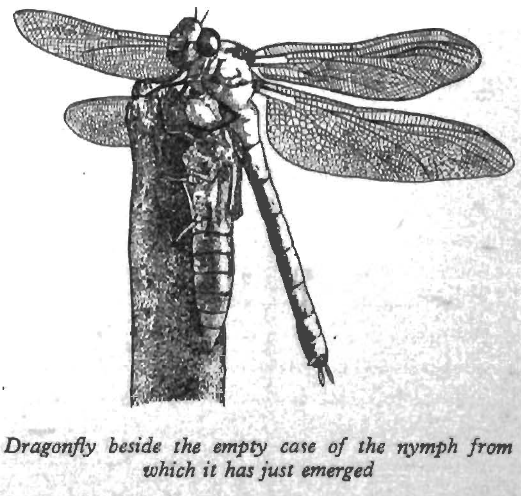
1. *Larva of lobster.* 2. *Larva of crayfish*
The former has fringed swimming appendages and the latter has well-developed claws for hanging on to its mother



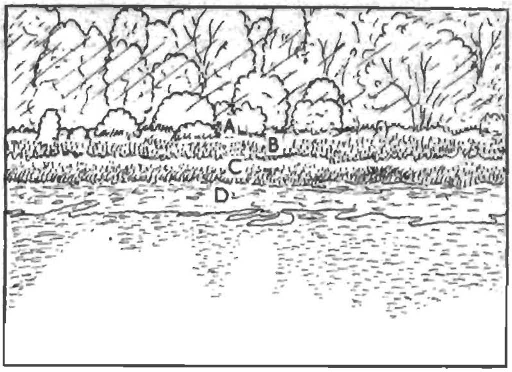
Female crayfish with eggs attached to appendages on the underside of the abdomen

drying of the wings in such flies is particularly rapid so that they can fly away almost immediately. The special problem of emerging in fast-flowing water is described on p. 47.

The life-history of insects shows a feature common to freshwater life, derived as it is largely by invasion from the land. The invaders retain to a greater or lesser extent the character of their ancestry. Some insects, such as flies, dragonflies, mayflies, stoneflies, and alder-flies, have retained a terrestrial adult stage, while others, such as most of the beetles and bugs, have become aquatic throughout life. There is a variation also in the degree to which methods of egg-laying, or of emergence of the adult, have departed from terrestrial custom. The alder-fly lays eggs on plants out of water, for instance, while some dragonflies descend below the surface for this function; and in midges the eggs themselves are adapted to water. Only rarely has the change from the ancestral condition gone so far that the origin can no longer be traced.



Dragonfly beside the empty case of the nymph from which it has just emerged



Photograph and diagram of the margin of a large woodland pond in Epping Forest. A–D *are the zones charted in the histogram on p.* 42

LAKES AND VEGETATION ZONES

A LONG train journey shows us a varied assortment of types of country, the changes from one to another being in large measure due to the differences in the vegetation. We can detect similar changes even in the course of a short walk, which may take us, for instance, at one stage over a chalk hill with its characteristic flora of wild thyme and marjoram, and at another through a quite different association of plants in a marsh at the foot of the hill. Each species of plant, and animal for that matter, needs a particular type of environment in which it can live and thrive, and this naturally determines its distribution to a large extent. In no sphere of life is this better seen than in the animals and plants of fresh water. Quite different associations are found, for instance, in rivers and in ponds, and even in the different parts of the same lake.

Most large lakes, as distinct from ponds, have a wide variety of features. Here there may be a sheltered bay with thick vegetation along the margin; there a stony shore exposed to wave action, and almost devoid of life; nothing but submerged vegetation may be present in one place where the water is deep, while only a few yards away it may be shallow enough for rushes and other plants to rise out of the water.

The belts of vegetation along the margin, sometimes very broad, are often of very different composition at different distances from the shore. At the two extremes there may be marsh or even terrestrial plants along the landward edge, and fully aquatic, submerged, or floating vegetation on the lakeward side. In between the two there may be more or less of a gradation. The illustration on this page shows a section of a marginal belt with some of the plants in the sequence in which they are usually found. One can recognize three fairly well defined zones:

1. MARSH ZONE, consisting of waterside plants with their roots in damp soil but no standing water between them. Typical plants are marsh marigold, meadow-sweet, water mint, marsh pennywort, and many of the rushes (*Juncus*) and sedges (*Carex*).

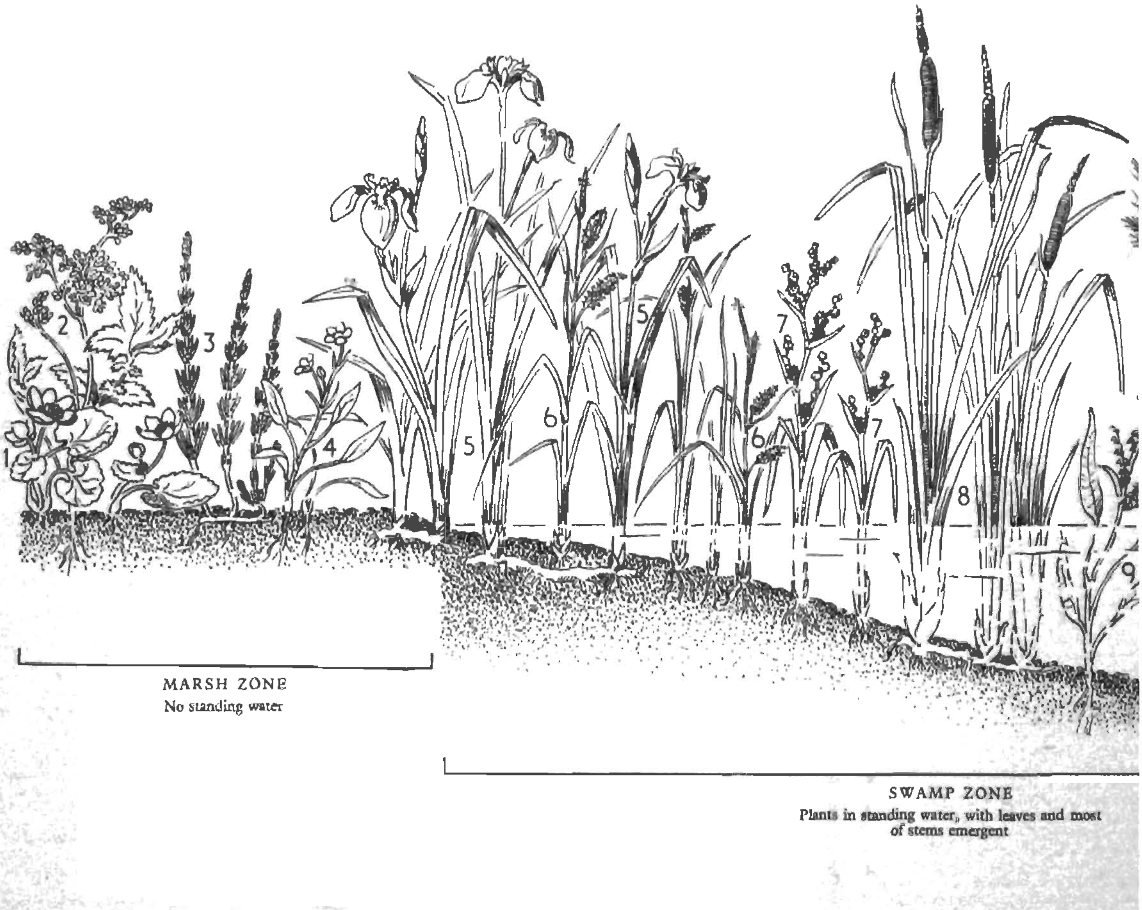
2. SWAMP ZONE, made up of semi-aquatic plants with roots and stem-bases under shallow marginal water and the stems and leaves rising into the air. It is often spoken of as 'emergent' vegetation, and is the most conspicuous to an

observer on the bank. Characteristic plants are flag, bur-reed, reed-mace, water-dock, common reed, bulrush, and a great many others.

3. ZONE OF TRUE AQUATIC PLANTS. This contains plants with all or most of their stems and leaves under water, although they often have some floating leaves and the flowers may rise up to or above the surface. The plants are rather obviously adapted to aquatic life in, for instance, the shape of their leaves. Within this zone there are three sub-zones:

(*a*) *Plants rooted in the soil with some floating or emergent leaves.* These are limited to fairly shallow water by the length of stem and leaf-stalk necessary to extend to the surface. Typical examples are the water-lilies, floating pondweed, some types of water buttercup and water starwort, arrowhead, and amphibious polygonum.

(*b*) *Rooted plants with stems and leaves entirely submerged.* Sometimes the flowers are also submerged, and so these plants can naturally extend into deeper water if it is clear enough, but if it is cloudy they are limited to shallower parts because sufficient light for the needs of green plants does not penetrate very deep. In very cloudy water, plants of this type may be quite absent for want of light. Canadian pondweed,



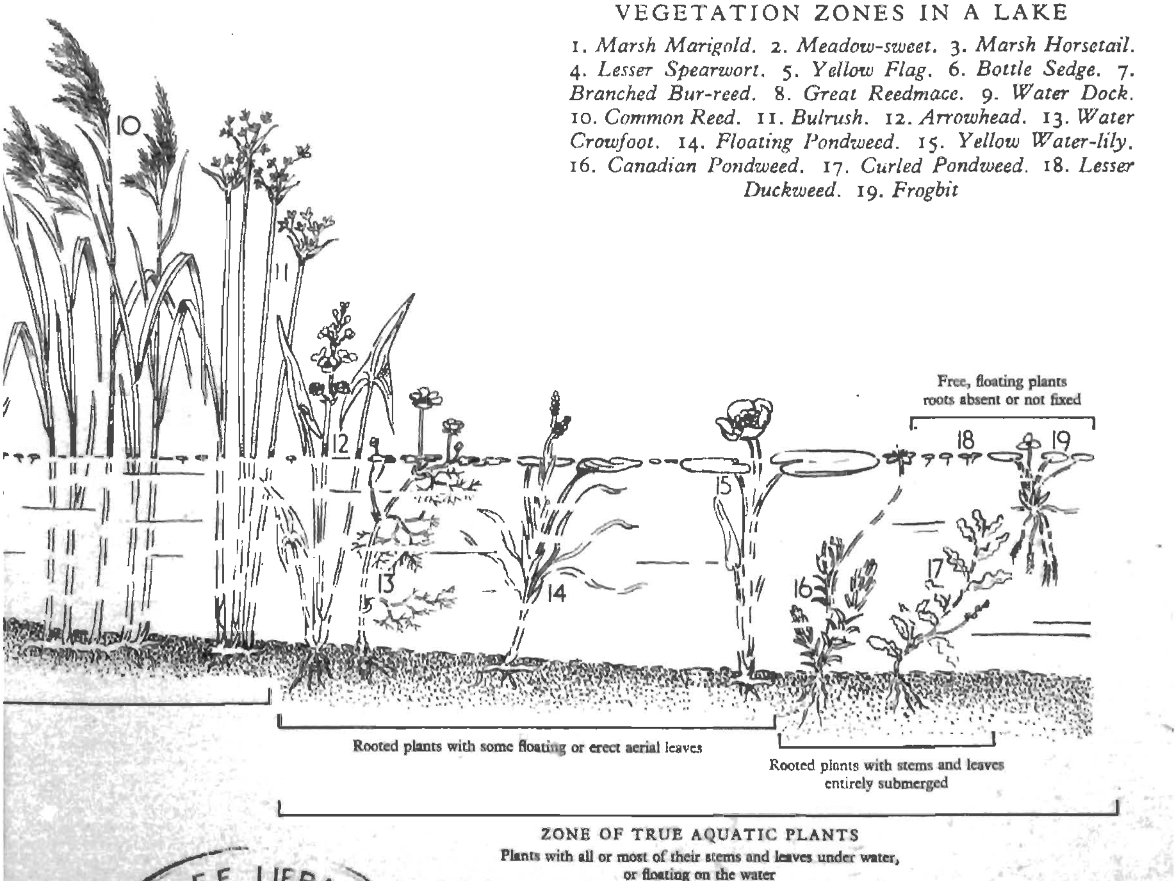
several pondweeds, hornwort, and a number of other flowering plants, and also the stoneworts, belong to this sub-zone.

(*c*) *Unfixed or free-floating plants.* These usually have roots which merely hang down into the water and are not fixed in the soil. The leaves are usually entirely of the floating type and support the plant at the surface. In theory, such plants are not restricted in distribution either by depth of the water or by light shortage, but actually they are usually more or less interspersed with plants of sub-zone (*a*) or even with swamp plants, rather than forming a separate community of their own. Many of the plants are small, such as the duckweeds and the beautiful water fern *Azolla*, but there are a few larger ones such as frogbit and water-soldier.

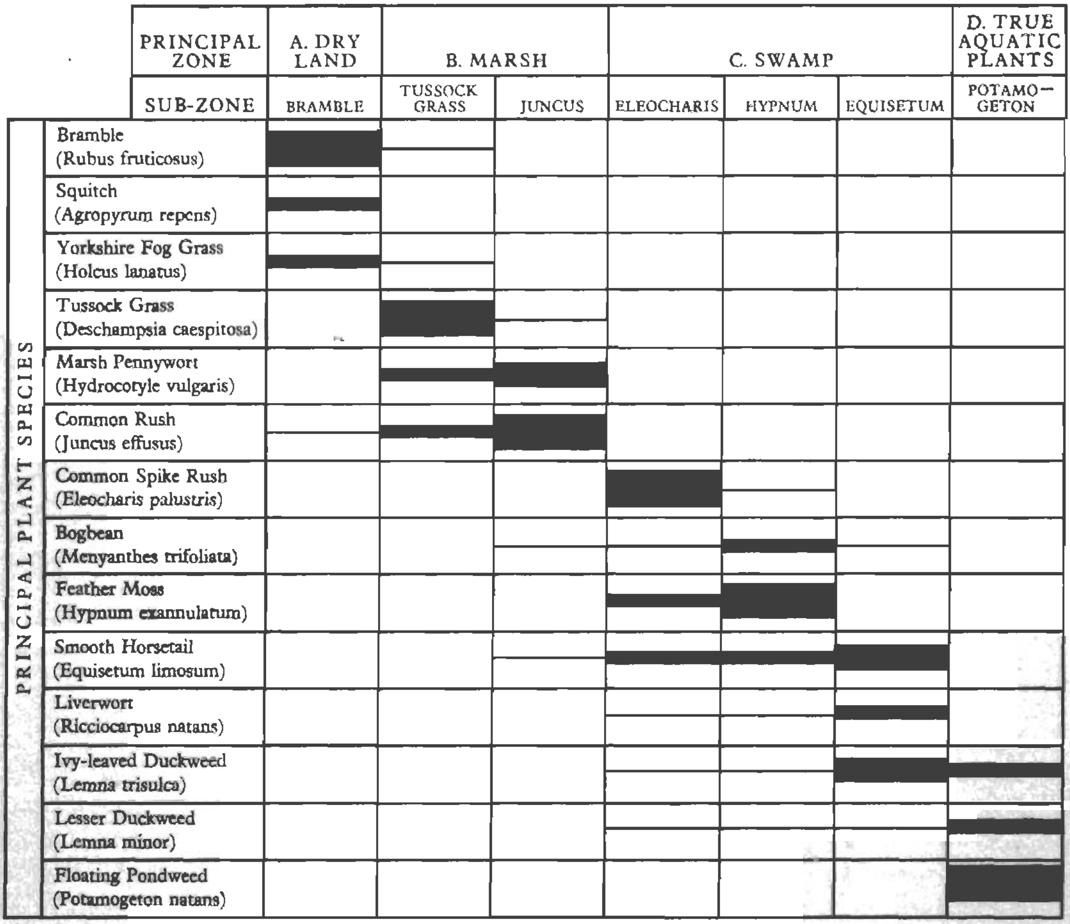
All these zones do not necessarily occur in any one lake, and their relative widths and the regularity of their distribution may vary with the steepness of slope of the bottom. Vegetation is often zoned in large ponds. It is interesting to study zoning by means of a 'transect', which is a system used widely by botanists to show up the details of a gradual change-over from one kind of plant community to another. A length of string or rope is laid down across the zones (that is, at right angles to the margin of the lake),

VEGETATION ZONES IN A LAKE

1. *Marsh Marigold.* 2. *Meadow-sweet.* 3. *Marsh Horsetail.* 4. *Lesser Spearwort.* 5. *Yellow Flag.* 6. *Bottle Sedge.* 7. *Branched Bur-reed.* 8. *Great Reedmace.* 9. *Water Dock.* 10. *Common Reed.* 11. *Bulrush.* 12. *Arrowhead.* 13. *Water Crowfoot.* 14. *Floating Pondweed.* 15. *Yellow Water-lily.* 16. *Canadian Pondweed.* 17. *Curled Pondweed.* 18. *Lesser Duckweed.* 19. *Frogbit*



and at regular distances along it an estimate is made of the abundance of each species of plant. There are various methods of doing this. The best is to use a square frame of stiff wire or wood, which at each distance can be laid down at random at several points, and the number of times each species turns up in the frame is a rough measure of its abundance. If the abundance of a plant at each level is expressed as the percentage it forms of all the plants occurring there, it is possible to draw a 'histogram' which shows clearly the changes in vegetation along the line of the transect. The one illustrated largely explains itself, and is drawn up from a transect of the locality shown in the photograph on page 39. Within each main zone one usually finds that different plants are dominant at different levels, so that sub-zones are recognizable, which may be conveniently named, as in the histogram, after the dominant plant.



HISTOGRAM OF THE VEGETATION IN THE LAKE ILLUSTRATED ON pp. 39–41

The thickness of the line denotes the percentage each species forms of the total vegetation at each sub-zone

VERTICAL ZONES

We have seen that if you wade through a vegetation belt in the right direction you will pass through a series of communities of living organisms which differ more or less from one another. If you could start at the bottom of a lake, and rise to the surface, you would pass through another series of zones. This is a vertical one, starting with plants and animals such as mussels, snails, and the larger crustaceans living on the bottom, through mid-water, inhabited by actively swimming fish, until at or near the surface you would find, apart from any of the larger floating plants already described, a whole host of free-floating plankton, which drifts about at the mercy of any current which is flowing. Most of these organisms can only be seen with a microscope, for the most abundant are extremely minute one-celled animals and plants such as diatoms and desmids. They need a special net with a very fine mesh to collect them, and are difficult to study. There is one insect, however, which is perhaps best included in the plankton although it can move to some extent by its own efforts; this is the very remarkable 'phantom larva' of a small gnat-like fly called *Chaoborus*, which often abounds in lakes, but can also be found in most ponds. Its whole body is almost completely transparent except for two pairs of air-sacs, one towards each end of the body; these are all that remains of a tracheal respiratory system, here adapted for another purpose. The sacs can be enlarged or made smaller by secreting gas into them or by the removal of some of it, and they are used to adjust the level of the insect in the water, and even to maintain a horizontal position when weighed down at the front end by its prey, which is caught by the peculiar antennae. It spends its time drifting in mid-water or near the surface, and this no doubt protects it from any enemies below, to which it will be almost invisible; but if it should be detected and attacked it has a second line of defence, for by means of a sudden wriggle it can jerk itself about 3 inches away in an unpredictable direction so rapidly that it is difficult to follow, and its bewildered enemy has to start looking all over again. It has a small vertical tail-fin made of a fan of feathered hairs which may be useful in locomotion, but more probably acts like the keel of a boat to keep the larva the right way up in the water. All these things can be seen with a few larvae in a glass dish in which it is fairly easy to spot them.

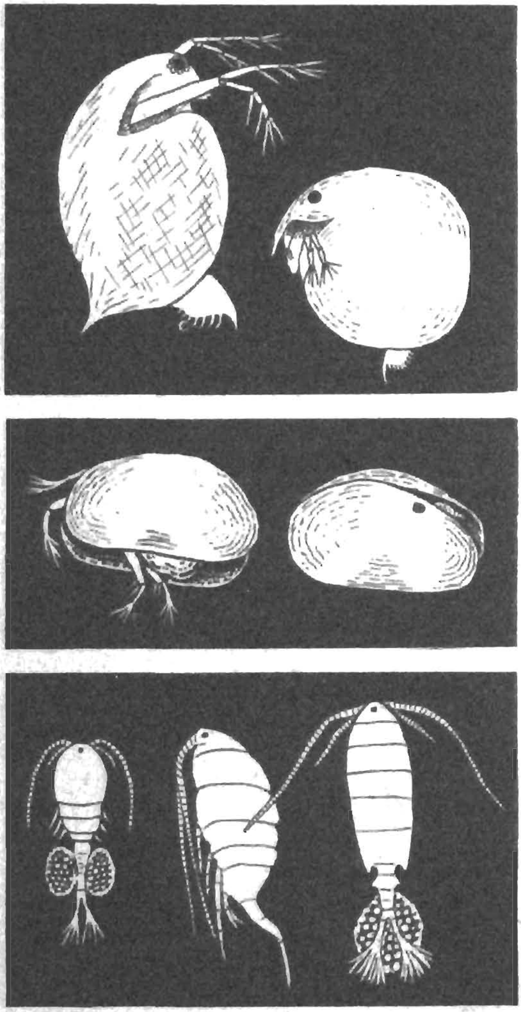
PONDS AND DRYING UP

What is a pond? There are many lakes which some people call ponds, and vice versa. One way of distinguishing them is that a pond is shallow enough to have rooted vegetation all over it. This may hold good in most cases, but sometimes very large expanses of water, which one would not hesitate to call lakes, have vegetation more or less throughout, while modest cattle ponds may be quite without vegetation in the centre. There is, in fact, no easy distinction between the two categories, but, in order to see some of the really characteristic features of the life of ponds as opposed to lakes, we shall confine our attention to bodies of water so small that they are liable to dry up in summer.

The drying up of a pond is a severe danger to its living inhabitants, for it deprives them of their home. They can only avoid disaster in one of two ways. Either they must tide over the drought by producing a form which can rest in the mud or soil, or they must get out and migrate to other ponds which have not dried

up. Both of these methods are in fact used by different animals.

A pond which I had under observation for some time had previously been dry for a few years, and soon after it was refilled there appeared in it a few kinds of aquatic animals in rather large numbers, which included the following:



Small crustacea common in ponds

Top: *Water-fleas* (Daphnia *left*, Chydorus *right*), Centre: *Ostracods* (Eucypris) *with valves of shell open during swimming (left) and closed (right)*. Bottom: *Copepods* (Cyclops *left*, Diaptomus *centre and right*); *note the egg-sacs*

Molluscs: *Limnaea truncatula* (a small pond-snail).
Pisidium personatum (a very small pea-mussel).

Crustacea: *Daphnia obtusa* and *Chydorus sphaericus* (water-fleas).
Diaptomus castor (a copepod).
Eucypris virens (an ostracod).

There is no doubt that these had persisted over the dry period, which they are known to be able to do. The snail is actually only semi-aquatic, and no doubt remained active in the damper places, even in the absence of water. The mussel can dig down into the mud, close the valves of its shell, and so avoid drying up. It produces young viviparously when favourable conditions return.

Of the crustacea, *Daphnia* and a few other water-fleas are well known to be able to withstand drought. At the appropriate time of year, or under unfavourable conditions, they produce special eggs, usually laid two at a time and enclosed in the brood pouch which the female sheds when it moults. In this form the eggs can remain dormant or inactive for a very long time and still develop when the pond fills up again. A spell of rapid reproduction then follows for several generations, only females being produced and their eggs developing without the necessity of being fertilized; and so a dense population is built up rapidly making up for time lost during the drought. *Diaptomus* and *Eucypris* also lay drought-resistant eggs. The eggs of ostracods, and those of *Daphnia* also, have been known to survive drought for 20 years or more.

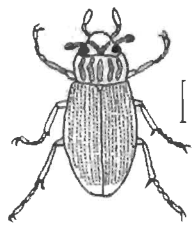
The Fairy Shrimp lays drought-resistant eggs. I once kept some adults in a pie-dish for some time, and allowed the water in which they had lived to evaporate. After some weeks the dish was filled with water again, and it was not long before it contained numbers of young Fairy Shrimps which had hatched from eggs laid by the earlier inhabitants. What better illustration

could one want of the value of resting eggs to an inhabitant of small and unreliable ponds?

Certain kinds of mosquitoes lay their eggs in summer, at a time when their favourite ponds are empty; the eggs are therefore deposited on dry ground, and the females seem to be very successful in selecting hollows where the winter rains will produce ponds, for abundance of young larvae can usually be found in such places very soon after the water has appeared. This is another instance of resting eggs, but they are still further adapted to the special conditions, for the eggs do not all hatch on the first wetting. Some remain unhatched as a safeguard, in case the wet weather has not come to stay and the pond dries up again. They may hatch only at the second or third wetting. Thus some at least of the larvae will have avoided an early death through drying up.

Emigration is largely confined to insects with wings. Water-beetles and water-bugs are perhaps the most familiar examples. Any small patch of water (even a tub or bath in the garden) will, if exposed, collect beetles, water-boatmen, and pond-skaters, especially in summer when the numbers of migrating *Helophorus* and other water-beetles may be enormous. Much can be learned by placing a flat bath of water in a well-exposed part of the garden, and making regular collections of all the living things appearing in it throughout the year. A great deal is not yet known about migration, and there is a good chance of making new discoveries. A bath which I put out one summer collected 128 beetles between 8 and 26 June, most of them belonging to one species of *Helophorus*. During a part of this period, when the beetles were turning up in the greatest numbers, a neighbouring pond where they were abundant happened to be just drying up, and they were evidently looking for other accommodation. The insects which migrate most readily are those which normally inhabit small ponds liable to dry up.

There are, of course, many aquatic animals which cannot fly. These must either migrate



A water-beetle which frequently migrates: Helophorus

Water-mite attached to the leg of a water-boatman

over land, which is out of the question except for larger amphibious creatures such as newts and frogs, or they must 'get a lift'. There is little doubt that eggs, or even adults in the case of very small animals, get accidentally carried from one pond to another on the feet of birds or cattle. We have seen how resistant some eggs can be to drying up; mud may stick to the feet of a wading animal and remain there for days, and the drought-resistant eggs which it is almost sure to contain sometimes will survive, and get washed off at a later visit to another pond.

There are certain animals which are specially adapted for 'hitch-hiking' from pond to pond. The water-mites have an intricate life-history which includes parasitic early stages, some of which cling to the feet of water-boatmen, or conceal themselves under the wing-cases of *Helophorus* beetles. These insects may migrate to other ponds before a later, free-living stage of the mite hatches out. Some mites live on the outside of dragonfly nymphs and transfer to the adult as it emerges from the larval skin; they then get the advantage of aerial transport. *Vorticella* and other small animals related to it often live attached by their stalks to water-insects, which distribute them not only within one pond, but from one to another if the insects can fly.

Not all ponds, of course, are of a temporary nature. Those which contain water all the year round have a fauna more closely resembling that of lakes. Such ponds are often richer than any other bodies of water in animal life, and contain a wide variety of types.

A water buttercup (Ranunculus fluitans) *growing in swiftly flowing water*

RIVERS AND TORRENTS

CONDITIONS in rivers vary more than in other types of water, owing to wide differences in the rate of flow. In broad, sluggish stretches, there is a close similarity to the conditions found in lakes, and the animals and plants are then very similar also. The faster a river flows, the more can we recognize in it a distinct community of animals and plants, which are perhaps more highly adapted to their special conditions of life than those of any other type of habitat. The features of these organisms are a curious mixture of protective measures against the violence of the current on the one hand, and of methods of exploiting it on the other.

Plants with broad, thin leaves would soon be torn to shreds in a brisk current, and one finds none. Nearly all the vegetation has foliage of a thread-like type. The more usual form of water buttercup with leaves of two types (p. 31) is replaced by *Ranunculus fluitans*, in which all the leaves are thread-like, with long flexible segments which trail downstream and do not offer enough resistance to the current to suffer severe damage. Apart from this, there is little in the faster flowing stretches except mosses (especially *Fontinalis*) and thread-like algae which cling to the stones and trail before the current in the same way. Where the flow is a little less rapid, there are the narrow, strap-shaped leaves of the simple bur-reed, certain forms of water starwort, and some completely submerged species of pondweed.

If you wade in shallow rapids and dislodge the boulders with your foot, at the same time holding an open net downstream, you will soon collect a good sample of the animal life. One

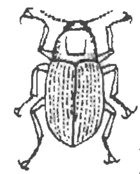
The very thin thread-like leaves of a water buttercup (Ranunculus fluitans)

of the gravest dangers which threatens these animals is that of being dislodged and washed downstream to places where conditions may not suit them. Many of the smaller animals avoid this by lurking beneath boulders or in the thicker growths of *Fontinalis* and *Ranunculus*. Some of them, such as the nymph of the mayfly *Ecdyonurus*, have in addition a flattened form enabling them to cling to the stones very closely while the stream is diverted over their backs. The nymphs of some of the stoneflies are also flattened, to a more moderate degree. The leech *Glossiphonia* is of similar shape, and its concave under-surface provides a cavity in which its eggs, and the young which hatch from them, are protected from being washed away. Most of the caddis-fly larvae build strong cases of pebbles to protect them from the grinding action of stones (another danger on an unstable bottom); *Silo* attaches large stones to the side of its case which flatten it, deflect the current, and act as sinkers to prevent its being washed away; *Agapetus* larvae build somewhat flattened cases which on pupation are glued down on to the larger pebbles, often in enormous numbers. The Miller's Thumb, a common fish among the moss-covered stones of rapids, has a flattening of the body which doubtless serves the same function. The tiny beetle *Elmis* avoids dislodgement differently, by having unusually long, hooked claws to cling on to the vegetation; it can hang on safely even in the rapid waterfalls which are its favourite home. The ways in which the young stages of some animals avoid being washed downstream have already been described (pp. 36, 37).

Besides those mentioned above, many insects maintain a precarious foothold among the boulders and mosses. These include several other stonefly and mayfly nymphs, a few beetles, larvae of flies, and, most interesting of all, a fine water-bug called *Aphelocheirus* (p. 48). Before insects could live in such a place, they had to overcome the difficulty of respiration. It is one thing for them to live in ponds and rise frequently to the surface to breathe the air their ancestors breathed; but it is quite another to live in a rapid stream which will wash them away if they venture to leave the comparative safety of the boulders and weeds. They have had therefore to become true aquatics and breathe under water. Some of them have blood-gills or breathe through the general body-surface (larvae of midges), more have tracheal gills (nymphs of mayflies and stoneflies), while *Aphelocheirus* and *Elmis* have air-stores modified into a plastron (p. 19) which also enables them to remain permanently submerged.

Insects which have a delicate, winged adult stage are confronted with yet another danger when they emerge; if the pupae were to rise up and rest at the surface for this purpose, as those of mosquitoes and many midges do in the still waters of ponds and lakes, they would get

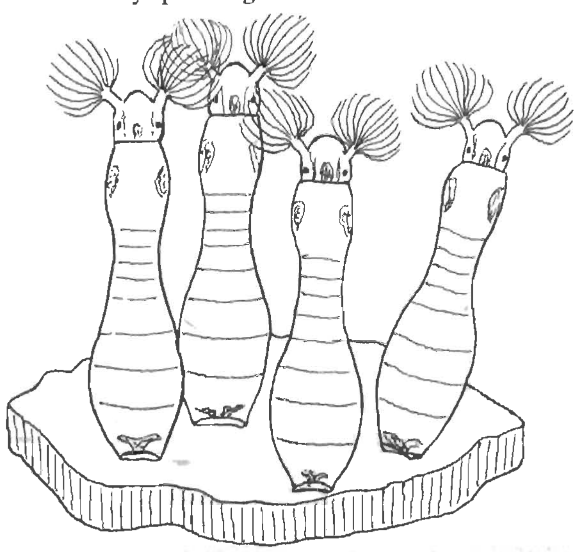
A bug (Aphelocheirus) *which inhabits the bed of rapid rivers*



A water-beetle (Elmis) *with strong claws. Much enlarged*

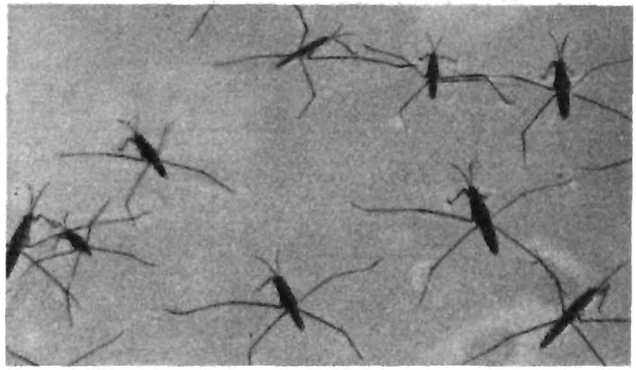
swirled away in the current and be unable to emerge successfully. In the buffalo-gnat, however, the adult becomes surrounded with a bubble of air while still in the pupal skin on the bottom; when the skin splits, the bubble escapes and rises with the adult in it, ready to run quickly over the surface to some support immediately the bubble bursts. It is protected from getting waterlogged during this adventure by a coat of close-set hairs.

The larva of the buffalo-gnat, on the other hand, turns the current to its advantage for two distinct purposes. Mostly it chooses the swiftest flow available, often in or near a waterfall, and with its filter apparatus extracts small food particles from the water; the faster the water flows over it, the more food it gets. Larvae of certain caddis-flies also use the current to bring food, but extract it from the water by spreading a silken net. The other way in which the buffalo-gnat larva exploits the current is connected with a safety device; if dislodged, it releases its hold on its support, and at the same time fixes a silken thread to it, and as it gets carried off downstream spins more silk so as to lengthen this thread to 6 inches or more; it then stops spinning, and remains anchored by its life-line, along which it later returns upstream to its original starting-point. This habit was no doubt evolved as a means of recovering after accidental dislodgement, but can be used to escape from enemies also. It has, incidentally, a close parallel in the larvae of certain moths living on trees, which when threatened let themselves fall from the leaves on a silken thread, up which they can climb again later when the danger is past.



Group of buffalo-gnat (Simulium) *larvae on a stone with feeding brushes spread to strain food particles from the water*

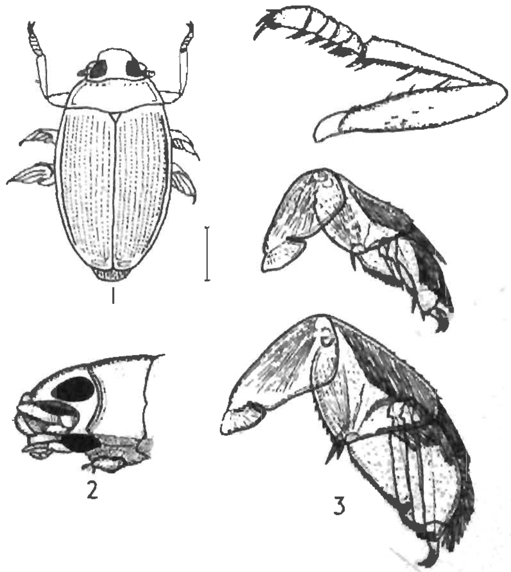
SURFACE FILM



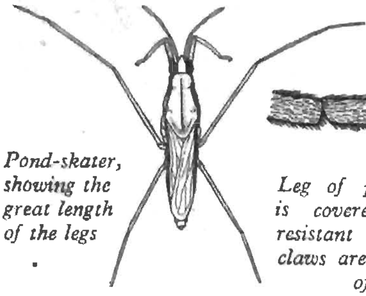
Pond-skater (Gerris) *on the surface of the water*

ONE would think that the film at the water surface would be too precarious a situation for animals to make their abode on it. And yet, in view of its peculiar properties, a small animal can, if light enough and of the right form, remain permanently supported on the top of the film, and can even maintain a very active existence there. In fact, we find here some of the most lively of insects, such as the familiar whirligig beetles (*Gyrinus*), and the pond-skaters (*Gerris*), which glide swiftly away over the surface when disturbed. Doubtless they have to be alert, for they have enemies both above and below the water; and the whirligig beetle has each eye divided into two quite separate parts, one on top of the head directed upwards into the air, and the other downwards into the water; thus it can keep an eye (or part of one) on both parts of the environment which concern its welfare. It has very peculiar paddle-shaped legs and can move with astonishing speed over the surface. It can also dive and swim with equal rapidity under water, and, when we realize that it flies readily in addition, we have to admit that its conquest of the elements is remarkably complete.

The pond-skater, although unable to go under water, is scarcely less adept on the surface than the whirligig beetle. Its most obvious feature is the great length of its legs, especially the second and third pairs, which stretch out horizontally so that a considerable part of their length is in contact with the water. They have a covering of short, close-set hairs, which, together with the curious position of the claws on the side of the leg, prevents them from breaking through the surface film. The greater the length of the legs, the stronger is the support they give to the body (a large Chinese pond-skater has the hind legs about 4½ inches long).



1. *Whirligig Beetle.* 2. *Head from side (note the divided eye).* 3. *Front, middle, and hind legs. Notice how the hind legs become flatter and wider*



Pond-skater, showing the great length of the legs

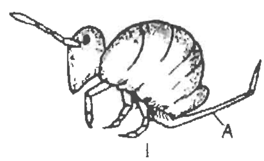
Leg of pond-skater. It is covered with water-resistant hairs and the claws are not at the end of the leg

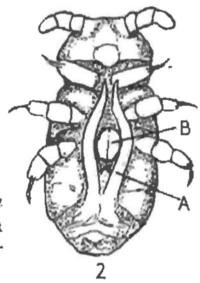
The water-bugs *Velia* and *Microvelia* are similarly constructed and supported, but *Hydrometra* differs somewhat, since its body is so thin and light that it can get enough support from the mere tips of its long legs, the pressure of which forms tiny dimples on the surface film. All its six legs appear to be necessary for support, however, while in *Gerris* the front pair are largely freed from such duties, and can be used for manipulating food.

Certain spiders which live at the margin, but can run rapidly over the surface when disturbed or when seeking their prey, make use of a coat of velvety hairs on their legs and body in the same way as the insects described above.

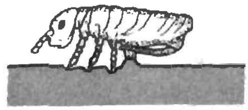
On stagnant water in sheltered places, often where there are floating or emergent leaves of water plants, one seldom fails to find the exceedingly small and primitive wingless insects called springtails. Their chief interest is the possession of an apparatus for hurling themselves violently into the air. The hind part of the abdomen is drawn out into a pair of filaments which are bent under the body and embrace a knob protruding from the underside of the thorax. These filaments can be forced downwards and backwards by means of muscles, but do not relinquish their hold on the knob until the strain becomes great, so that the sudden release jerks the insect into the air. Most springtails live in or on the soil (more especially damp soil), but *Hydropodura* is more at home on floating leaves and even on the water surface itself. It has a covering of very short velvety hairs, and is so small and light that not only will the surface film support its weight at rest, but it can even jump from it and land again without breaking through. The knob on the underside of the thorax, unlike the rest of the body, is hydrophile and attracted down on to the water, so that the insect automatically comes to rest right side upwards.

The surface film has been exploited for locomotion in quite another way. If a small particle of camphor is placed on water, it will sometimes move over the surface at some speed. This is because it dissolves in the water at one point more rapidly than at others; this lowers the surface tension at that point, so that the pull on the particle in other directions is greater. Small beetles (*Stenus* and some of its allies) move in a similar way; they are not truly aquatic, but live in vegetation overhanging the water at the margins of lakes, canals, or streams, so that they are in frequent danger of being dislodged on to the water. Although this proves fatal to many small insects, *Stenus* regains its home by gliding smoothly over the surface towards the bank

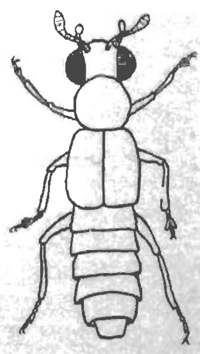




Springtails. 1. Sminthurides *from the side.* 2. *Young* Hydropodura *from beneath.* A. *Filaments for jumping.* B. *Knob*

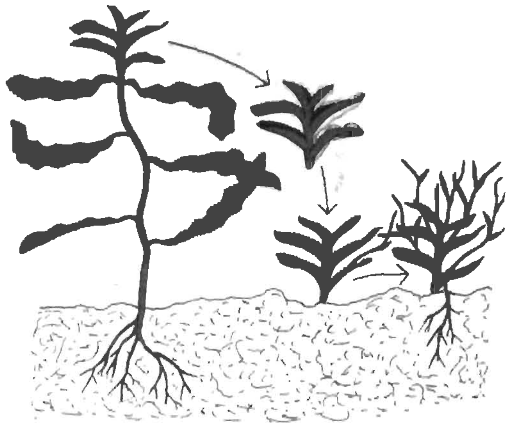


A springtail on the water surface. The knob attracts and adheres to the surface and the legs repel it



Stenus, *a beetle which moves in the water by secreting chemicals*

without any visible effort. The details have not been worked out, but it is assumed that the beetle secretes at its hind end a substance which has the same effect on the surface film as that of camphor. This is a very fine example of the exploitation by an animal of a physical feature in its environment.



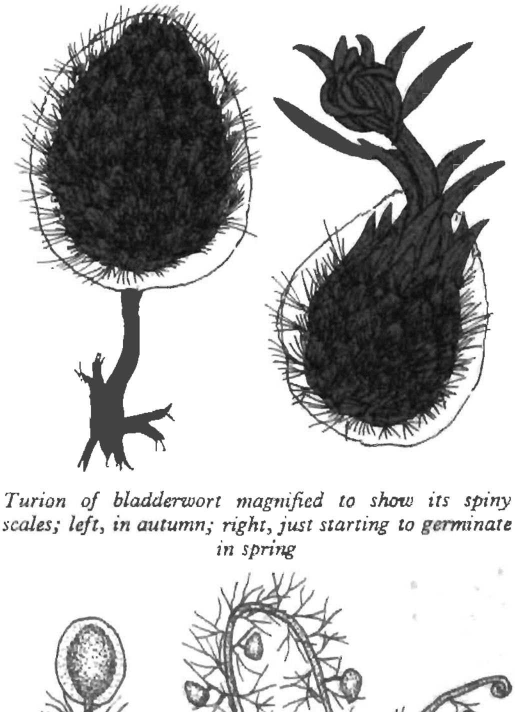
The formation and germination of winter buds of Curled Pondweed

FRESHWATER LIFE IN WINTER

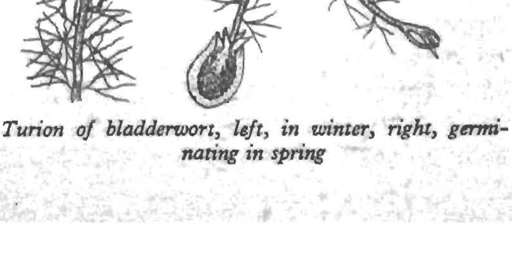
Terminal bud of Elodea

AN interesting part of the life-history of an organism living in cold or temperate climates is that which occurs in winter. Things living under water are at an advantage compared with land forms, for in the cold season they are sheltered in the water, the temperature of which hardly ever falls below 4° C. except at the surface. At this temperature many animals can remain active. If you lie flat on clear ice on a pond in mid-winter, you will be surprised at the signs of life and activity which can be seen beneath. Fish are, of course, on the move, although cold-blooded vertebrates on the land are hibernating in an inactive state. Most land insects, and such aquatic ones as live on the surface exposed to air, also hibernate. Sub-aquatic insects like corixid water-boatmen and many fly larvae, on the other hand, can remain active all winter.

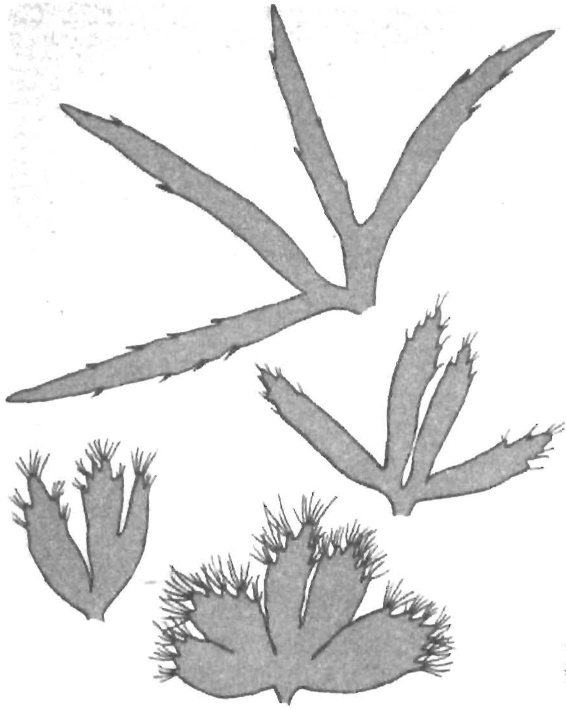
This behaviour of the animals is made possible by similar activity in the plants. Although emergent plants like reeds and water plantains die right down in winter, submerged ones such



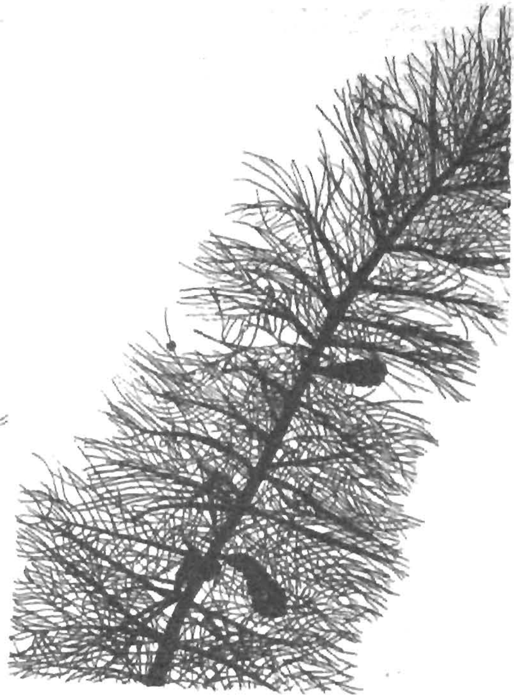
Turion of bladderwort magnified to show its spiny scales; left, in autumn; right, just starting to germinate in spring



Turion of bladderwort, left, in winter, right, germinating in spring



Scales of turion of bladderwort showing gradation from broad, spiny form at base to the typical leaf near the tip

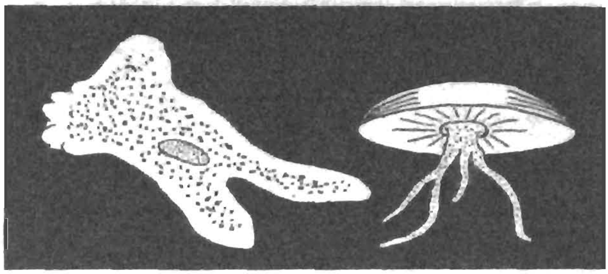


Turions formed from lateral buds in Water Milfoil

as many of the other flowering plants and microscopic algae keep alive, and retain green leaves all winter long, providing a never-failing food supply for animals.

In some flowering plants, at the approach of winter, special shoots or buds are produced at the tips of the stems, which become detached and sink to the bottom, where they lie dormant during winter; the rest of the parent plant dies and rots away. These winter buds, called 'turions', take root and sprout into fresh plants in spring, and thus perpetuate the species from year to year. Land plants very rarely do this because detached buds would perish in winter. Turions are really only specialized stems shortened and made compact, so that the leaves are packed down close on top of one another. This happens very slightly to the tips of the leafy stems of Canadian pondweed, but the parent plant persists all winter and the buds do not separate. In the curled pondweed the whole process takes place. A much more highly developed turion is produced by the bladderwort. In autumn a turion appears at the end of each branch in the form of a nearly spherical green bulb scarcely half as big as a pea. Dissection under a microscope or lens shows it to be made up of densely crowded, scale-like leaves on a much shortened stem, overlapping like slates on a roof or scales on a thistle-head. The outer scales near the base are broad, with little projections at the margin bearing tufts of bristles; these are so numerous that they form a dense felt, which, together with a covering of slime, protects the tender inner parts from enemies such as snails, which are said not to attack these curious objects. The scales are really modified leaves and there is a gradual change over towards the tip of the stem from scale to typical foliage leaves.

ANIMALS CLASSIFIED



Protozoa. Left, Amoeba; right, Arcella, *which dwells in a case. Much enlarged*

CLASSIFICATION is a convenient way of pigeon-holing species of animals and plants in groups along with others which they resemble. They are first arranged in small groups of only a few species, but these can, according to their similarities or differences, be arranged into larger groups, and so on, until all known animals can be placed into quite a small number of large and important groups called phyla. There are about sixteen of these phyla, eleven of which are represented in fresh water. Phyla are divided into classes, classes into orders, and orders into families. The three major types of unit are printed in different type thus:

PHYLUM, CLASS, **Order**

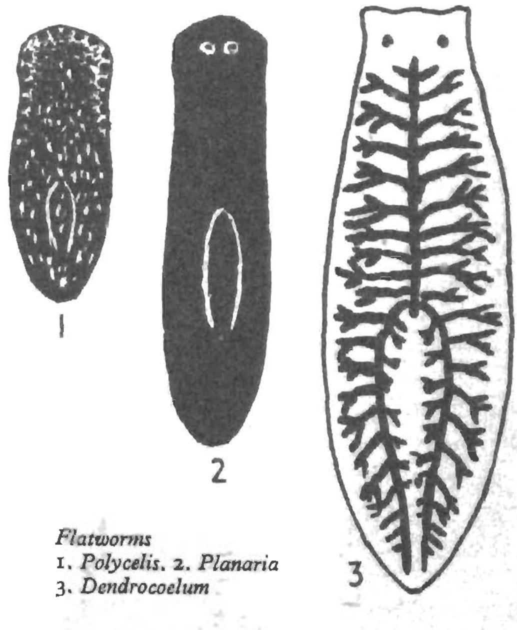
From the descriptions and figures below, it will be possible to recognize and classify most of the animals and plants found in fresh water whose way of life has been described in this book. Where examples have been figured elsewhere in the book, a page reference is given. Many are also shown in the frontispiece.

PROTOZOA

These are microscopic animals consisting of one cell only. A cell is a minute speck of protoplasm or living matter, and the bodies of larger animals and plants are built up of countless numbers of them. *Amoeba* can just be detected by the naked eye, but most protozoa are much smaller. The numerous species are placed in three main groups based on their methods of movement. (1) Amoeba and its relatives (the RHIZOPODA) creep by pushing out lobes or 'false feet' from the cell surface and flowing into them. (2) The FLAGELLATA (e.g. *Euglena*, p. 29) swim with one or more long flexible 'flagella'. (3) The CILIATA swim with a coat of short hairs or cilia which beat rhythmically (p. 29).

SPONGES (PORIFERA)

These grow and look like plants, but in their structure and methods of feeding they are really microscopic animals living in large colonies. Nearly all live in the sea, but *Spongilla* is found in fresh water (p. 20).



Flatworms
1. *Polycelis*. 2. *Planaria*
3. *Dendrocoelum*

Roundworms

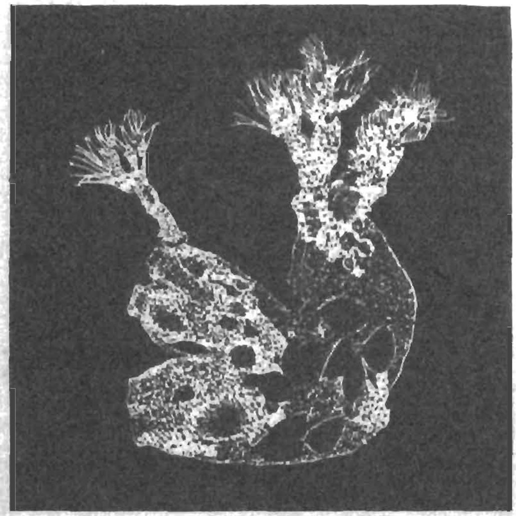
COELENTERATES

This is another principally marine group with very few freshwater representatives, only *Hydra* (p. 22) being well known. A green and a brown *Hydra* are both fairly common in ponds.

FLATWORMS (PLATYHELMINTHES)

This phylum contains the parasitic tapeworms and flukes, but also one class which lives in fresh water.

TURBELLARIA. These are flat-bodied worms about ½–1 inch long, which creep by means of cilia. The gut usually shows through the slightly transparent body. Most of them are dark brown or blackish, but the biggest one (*Dendrocoelum*) is whitish (p. 53).



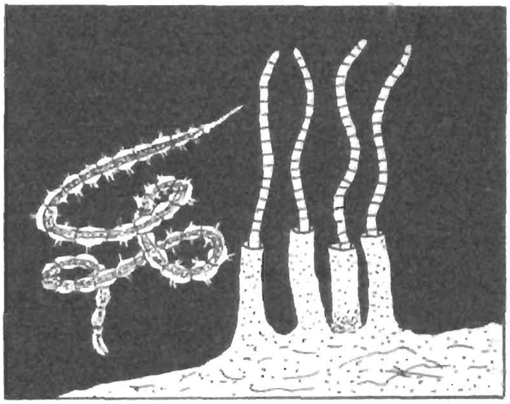
Lophopus, *a Polyzoan*

ROUNDWORMS (NEMATODA)

These abound everywhere, and although most are internal parasites, there are plenty of small ones (about 1 mm. long) in fresh water (even in drinking water). Like other worms they are cylindrical and tapered at both ends, but not segmented into rings like an earthworm. They move in a characteristic way, throwing their bodies into figure-of-eight curves.

WHEEL ANIMALCULES (ROTIFERA)

Although often very much smaller than *Amoeba* (the largest are about 2 mm. long),



Bristle-worms. Left, Lumbriculus; right, Tubifex *with 'tails' protruding from dwelling tubes*

these animals are many-celled and quite highly organized. They vary in shape, but usually have two distinguishing features (p. 20): a circular crown of cilia at the front end (hence the name 'rotifer' or 'wheel-bearer'), which is used both in swimming and in feeding; and a pair of conical processes at the other end, forming the 'foot', to attach them to objects while they are feeding.

MOSS-ANIMALCULES (POLYZOA)

These are small animals growing in colonies which encrust plant stems and other objects. Each animal secretes a house or sheath from which it protrudes a crown of tentacles; this recalls *Hydra*, but Polyzoa are much more highly organized internally.

TRUE WORMS (ANNELIDA)

These are worms with segments or rings and often prominent bristles along the sides. They move by contracting and extending the body rather than by bending it.

BRISTLE-WORMS (OLIGOCHAETA)

One or two of the earthworms, which belong to this group, are semi-aquatic, but the strictly aquatic worms are smaller. They are usually pink or red, but *Lumbriculus* is green. *Tubifex* lives in mud tubes in dense colonies.

LEECHES (HIRUDINEA)

These resemble ordinary segmented worms, but are often flattened, and have a sucker at each end. They generally move like a 'looper' caterpillar (but see p. 28).

MOLLUSCS

These are soft-bodied animals without any segmentation and usually have a hard external shell into which they can withdraw. Two classes are represented in fresh water.

SNAILS AND LIMPETS (GASTROPODA)

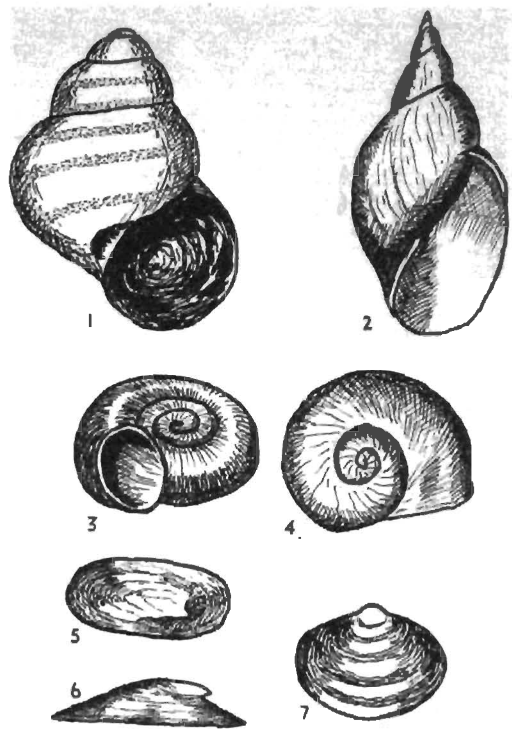
These have an undivided shell, spirally coiled in snails and conical in limpets. They are mostly found among water-weeds.

MUSSELS (LAMELLIBRANCHIATA)

These are 'bi-valves', with a shell of two halves joined by a hinge. They vary in size from the large swan mussel (p. 37), which may reach 5 or 6 inches in length, to the smallest pea-mussels of only a few millimetres. They are usually found in mud.

ARTHROPODS

Often there are more arthropods than any other animals in freshwater habitats, especially ponds. They are segmented like true worms, but this is often obscured by the fusion of segments. Unlike worms they have a hard outer skeleton, and paired appendages which are jointed like the legs and arms of a suit of armour. Representatives of three classes are found in fresh water.



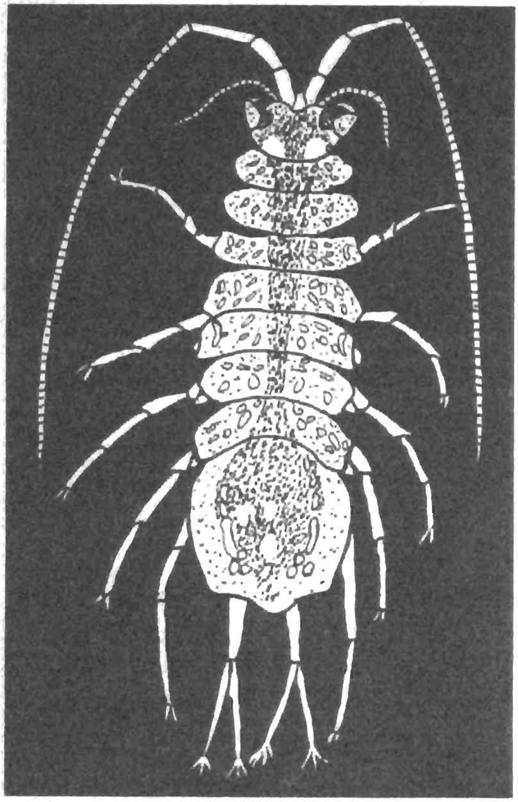
Some freshwater molluscs. 1. Vivipara. 2. *Large pond snail* (Limnaea). 3, 4. *Ramshorn snail* (Planorbis). 5, 6. *Lake limpet* (Ancylus). 7. *A small mussle* (Sphaerium)

CRUSTACEA

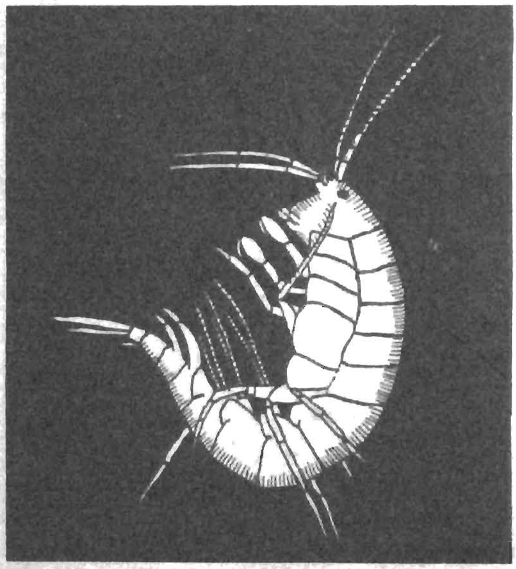
Lobsters and crabs belong here, but most of the freshwater types are very small, and need a lens or microscope to be seen well. They have two pairs of feelers or antennae; the body is divided into head, thorax, and abdomen, but the head and thorax are often joined up and covered by a common protective 'carapace', which may in some types completely enclose the body. The most familiar orders in fresh water are the following:

Water-fleas (Cladocera)

These are mostly about 1–3 mm. long. *Chydorus* (p. 44) is so small (about 0·3 mm. long) that it is easily overlooked. The carapace is flattened laterally, and looks as if it is bivalved, but is really all of one piece. *Daphnia* (p. 44) swims in jerks by means of its antennae.



Asellus, *an Isopod crustacean*



Freshwater shrimp (Gammarus)

Ostracods

These are rather similar to the water-fleas in size and shape, but the carapace is made of two hinged halves which can be drawn together by a muscle, so as to enclose the whole animal and make it resemble a bivalve mollusc rather than an arthropod. It can protrude its antennae from between the valves and bustle over the mud at great speed with their aid (p. 44).

Copepods

These are about the same size as the foregoing, but with a very characteristic, somewhat oval shape (p. 44), tapered at the hind end and with long antennae with which they can swim fast. There is no conspicuous carapace.

Water-lice or Slaters (Isopoda) and Freshwater Shrimps (Amphipoda)

Asellus and *Gammarus* respectively are the characteristic freshwater representatives of these groups. They are of about the same size, up to nearly an inch long, and whereas the water-louse *Asellus* is flattened on upper and lower surfaces like a woodlouse, the freshwater shrimp *Gammarus* is flattened on the sides, so that it rests on the bottom, or swims over it, on one side.

Decapods

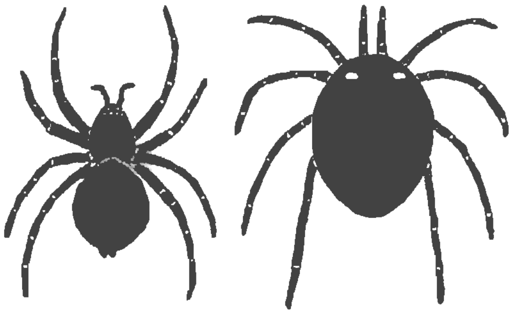
The crayfish is the only British freshwater crustacean of any size; it may reach a length of 4 inches, and is very like a lobster, with front legs modified into large pincers (p. 30).

Arachnids

These are arthropods with four pairs of walking legs and no antennae. In freshwater forms the segments are fused together and cannot be distinguished.

Spiders (Araneae)

These have a narrow constriction or waist in the centre of the body. There is only one true water-spider (*Argyroneta*, pp. 17, 18), but several



Water-spider and water-mite, the latter much enlarged. Note the spider's 'waist'

others live at the margin and sometimes run out over the surface of the water.

Water-mites (Hydracarina)

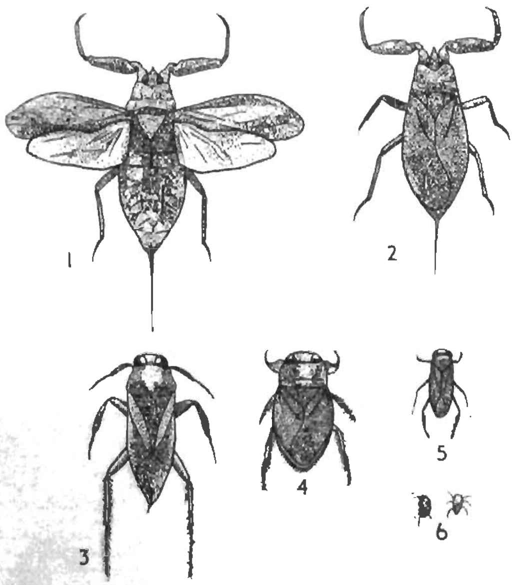
These have rounded or oval bodies without any constriction in the middle. They are usually about 2 mm. long, but sometimes up to 8 mm. Many are bright red in colour, and some are blue or green.

Insects

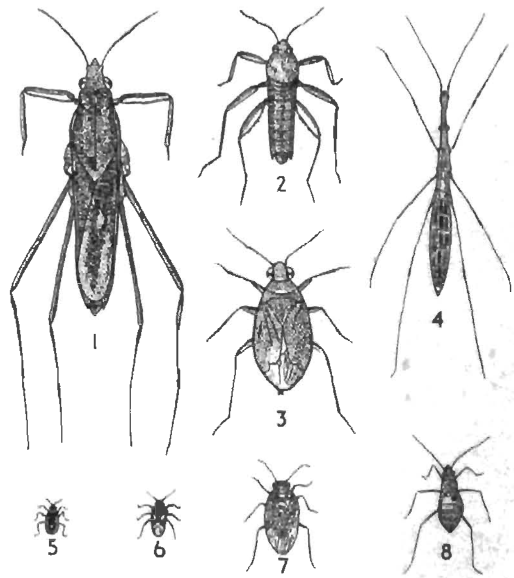
These are arthropods with three pairs of legs, one pair of antennae, and usually wings in the adult stage. The body is divided more or less clearly into head, thorax (to which legs and wings are attached), and abdomen. Often the adult is very different from the immature stages, the insect experiencing an abrupt change or 'metamorphosis' in its life-history. Apart from the primitive springtails, life-histories may follow one of two patterns:

'incomplete' metamorphosis	egg →	nymph (active) →		adult
'complete' metamorphosis	egg →	larva (active) →	pupa or chrysalis (passive resting stage) →	adult

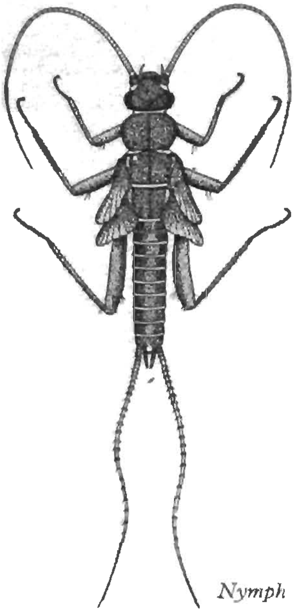
Some insects are aquatic only in the nymph or larval stage, while others spend all their lives in or on the water. The insects are an enormous group, and, of the 22 or more orders into which they are classified, 9 are well represented in



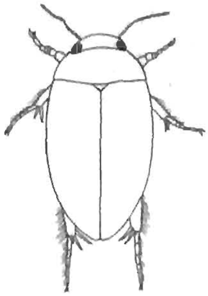
Water-bugs which live under water
1, 2. *Water-scorpion* (Nepa). 3. *Backswimmer* (Notonecta). 4. Ilyocoris. 5. *Water-boatman* (Corixa) 6. Plea



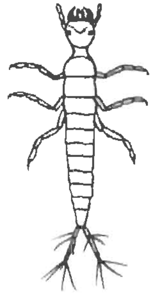
Water-bugs which live on the surface
1. *Pond-skater* (Gerris). 2. Velia. 3. *Shore-bug* (Salda). 4. *Water-measurer* (Hydrometra). 5. Microvelia. 6. Hebrus. 7. *Shore-bug* (Saldula) 8. Mesovelia



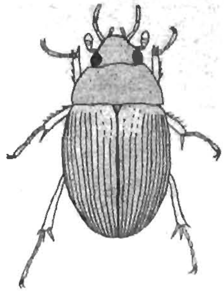
Nymph of Stonefly



A Dytiscid beetle (Agabus)



Young larva of Dytiscid beetle (Agabus)



A Hydrophilid beetle (Hydrobius)

fresh water and form an important part of the fauna.

Insects without metamorphosis

Springtails (Collembola)

These minute insects are without wings and live mainly in the soil, but a few live on the surface of the water (p. 50).

Insects with incomplete metamorphosis and aquatic usually in the young stages only

Stoneflies (Plecoptera), Mayflies (Ephemeroptera), and Dragonflies (Odonata)

These three orders have much in common, the nymphs being aquatic and the adults winged and aerial. Stonefly nymphs have two long 'tails', and are either without gills or have them on the thorax. Mayfly nymphs (p. 18) have three tails, and gills in two rows on the top or sides of the abdomen. Dragonfly nymphs are predacious, and of two kinds; large ones without external gills (p. 22), and smaller ones (those of the slender damsel-flies) with three flattened gills at the tip of the abdomen (p. 18).

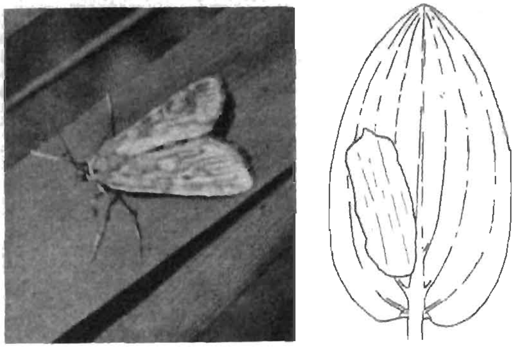
Bugs (Hemiptera)

The water-bugs are many and of diverse kinds, and aquatic in all stages. All have pointed, piercing mouthparts, often in the form of a proboscis, which they use for feeding. Some live under water, and have very short, almost invisible antennae: *Ilyocoris*, *Nepa* (water-scorpion), and *Ranatra* (water stick-insect) creep in vegetation or debris, while the water-boatmen swim actively, *Corixa* and its relatives the right way up, and *Notonecta* ('backswimmer') and the minute *Plea* upside down. Other bugs live on the surface film and have long antennae, *Gerris* (the pond-skater) and *Velia* being fairly large, while the slender *Hydrometra* and the diminutive *Microvelia* and *Hebrus* are easily missed.

Insects with complete metamorphosis

Beetles (Coleoptera)

Water-beetles are restricted to quite a small number of families, some of which are entirely aquatic while others only have some aquatic members. Most are aquatic in all stages, but sometimes the pupa may be buried in mud above the waterline. The best adapted are the Dytiscidae, which in the adult stage are strong swimmers and have a streamlined shape (p. 26). The Haliplidae are rather similar, but a look at the underside will distinguish them from the Dytiscidae (p. 17). The Gyrinidae are familiar as the brightly shining whirligig beetles which glide in ceaseless circles on the water surface (p. 49). The Hydrophilidae are not all aquatic, but those which are so are seldom well adapted and cannot swim at any



Left: *China-mark Moth.* Right: *Larval case of China-mark Moth on underside of leaf of floating pondweed*

speed; however, *Hydrophilus* itself, our biggest water-beetle, can swim well. *Donacia* has an interesting aquatic larva (p. 19). Among the Dryopidae are a few small, but interesting, beetles such as *Elmis* found chiefly in rapid currents (p. 48). Several other families are either small in numbers or have few aquatic members.

Alder-flies (Megaloptera)

Only the alder-fly (*Sialis*) is common in fresh water; its larva has thread-like gills on the sides of the abdomen and lives in mud (p. 18).

Caddis-flies (Trichoptera)

The larvae and pupae only are aquatic. In nearly all cases the larvae are easily distinguished by the tubular cases which they build of plant fragments, sand grains, or other convenient objects, joined together with silk. This provides them, and later the pupae, with a protective house (p. 15).

Moths (Lepidoptera)

The china-mark moth (*Nymphula*) and a very few others have caterpillars which live under water, some of them building cases after the manner of caddis-fly larvae.

Two-winged Flies (Diptera)

Certain families of flies have aquatic larvae, most of which are legless, and some of them are maggot-like. They differ widely in their structure and the way they are adapted to live in

Eric Hosking

Slavonian Grebe at its nest. Notice the webs on the toes for swimming

water, and provide some of the most abundant and fascinating members of an aquatic fauna. Some of the best known are the mosquitoes or gnats (Culicidae, p. 16), midges (Chironomidae), buffalo-gnats (Simuliidae, p. 48), horse-flies or clegs (Tabanidae), and chameleon flies (Stratiomyidae, p. 19). All these have very characteristic types of larvae. Other families have only a few aquatic representatives, such as the crane-flies (Tipulidae) and hover-flies (Syrphidae); the best-known aquatic type of the latter family is the rat-tailed maggot, larva of *Eristalis*, the drone-fly (p. 19). There are several other less well-known families whose larvae inhabit fresh water.

CHORDATA

The chordates are animals with backbones. The classes occurring in fresh water in Britain are as follows:

Fish (Pisces)

Many species. Sticklebacks are almost the only fish found in small ponds, but in lakes are found others such as pike, roach, and perch, and rivers provide a still wider variety including trout, salmon, and bullhead. Minnows are commonest in clear streams.

Amphibia

These are frogs, toads, and newts, which have an aquatic larval stage or tadpole (p. 27). This changes into the adult animal by a metamorphosis, but the change is gradual as compared with the metamorphosis of insects; it results in the loss of the tadpole's gills and the development of lungs which enable it to change to aerial respiration; in frogs and toads (**Anura**) the tail is absorbed also, so that the adult is without one, but in the newts (**Urodela**) this does not happen, and the adult is very similar in appearance to the tadpole, and spends more time in the water than adult frogs or toads.

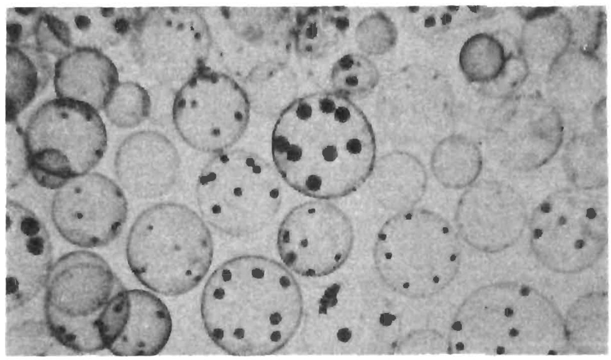
Birds (Aves)

Only a limited number of birds such as grebes, ducks, and Moorhens are sufficiently associated with and adapted to water to be called aquatic. Some of their adaptations have been described (pp. 23, 28).

Mammals

These, like birds, are warm-blooded, but differ in having fur and in suckling their young. The otter (p. 27), water-vole, and water-shrew are the only British mammals which live always associated with water, if we exclude those, such as the coypu, which have been introduced into this country by man.

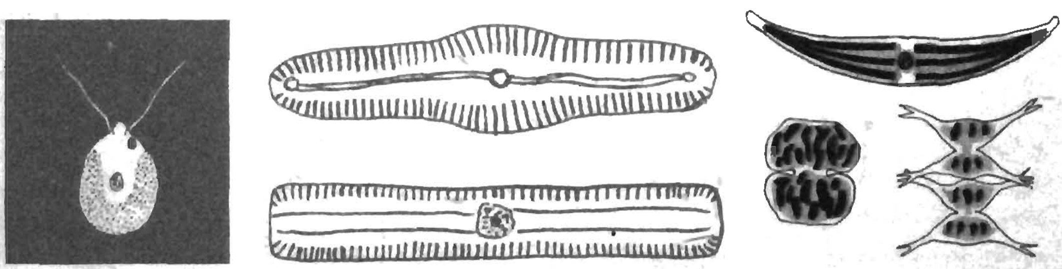
PLANTS CLASSIFIED



Colonies of Volvox

Harold Bastin

Plants are no less important than animals in the economy of aquatic life, but they fall into a smaller number of groups. If we exclude the bacteria (which, although of the greatest fundamental importance to life generally, are difficult to study and beyond the scope of this book) the



Left: *A single-celled green alga* (Chlamydomonas). Right: *Desmids*. Centre: *A diatom from different angles. All highly magnified but to different scales*

remaining aquatic plants can be classified into five fairly distinct groups, equivalent more or less to the phyla of animals.

ALGAE

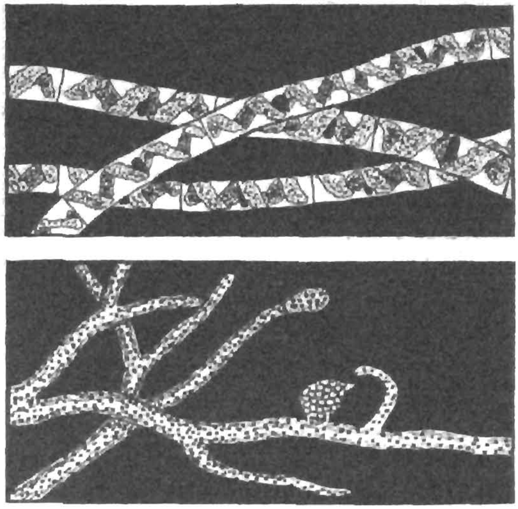
The vast majority of the most simple plants belong to this large and somewhat incongruous group. They are remarkable for their range of colour. The brown and red seaweeds are algae, but nearly all the freshwater forms are predominantly green, and smaller and simpler than seaweeds in structure, mostly requiring a microscope for their detection and examination. Out of the great variety of algae, six main types of structure can be recognized.

1. Single-celled green plants, corresponding to the protozoa amongst animals. *Chlamydomonas* is typical, and although microscopic is sometimes so abundant as to turn the water as green as pea soup. *Euglena* has been treated as an animal (p. 29), but could with as much justification be included here.

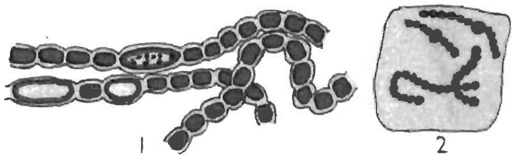
2. Highly specialized single-celled algae called desmids and diatoms, most of which are free-floating. In desmids the cell is constricted in the centre to form two halves which are exact mirror images of one another. Diatoms are yellow or brownish rather than green, and the cell wall contains silica (a glassy substance) and is made up of several pieces often richly engraved with parallel lines. It requires a powerful microscope to see all these details, but sometimes desmids and diatoms form larger colonies or long thread-like chains.

3. Colonial forms, such as *Volvox*, consist of a number (sometimes about 30,000) of cells like *Chlamydomonas* enclosed in a common spherical mass of jelly, the whole behaving in some ways like one individual and in others like a collection of separate ones.

4. Filaments, made up of long chains of cylindrical cells joined end to end like so many drain-pipes. The filaments form tangled masses,

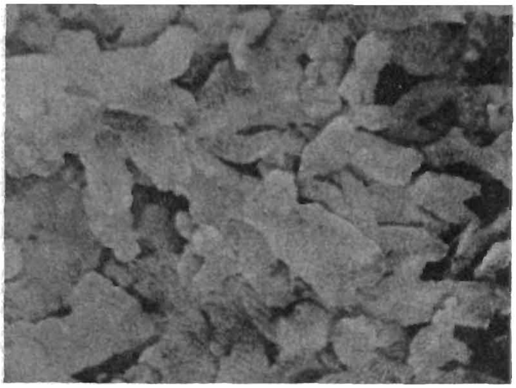


Green thread-like algae: above, Spirogyra, below, Vaucheria. *Highly magnified*

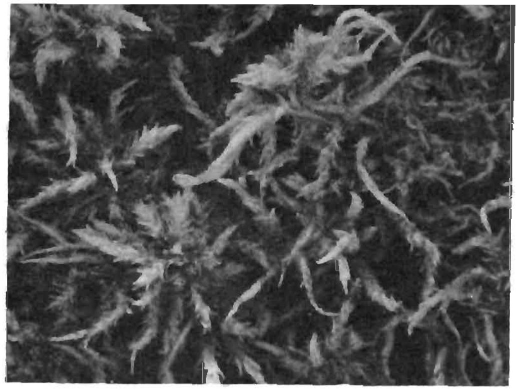


Blue-green algae: 1. Anabaena. 2. Nostoc

Stoneworts. 1. Chara. 2. *Part of plant of* Nitella. 3. *Fruit of* Chara *much enlarged*



A Liverwort which lives at the margin rather than under water



Harold Bastin

Sphagnum Moss

giving rise to the green slime which is so familiar in ditches and cattle-ponds. In *Spirogyra* the green colouring matter (chlorophyll) is contained in a spiral body coiled round the cell, while in others it is evenly distributed or in irregularly shaped bodies. In some (e.g. *Vaucheria*) there are no transverse walls in the filament between the cells.

5. 'Blue-green' algae are extremely simple, the cells containing no central body or nucleus as other cells do, and containing pigment which is blue-green rather than pure green. Usually the cells are in chains or colonies, embedded in a common mass or sheath of slime which is produced copiously by these plants.

6. *Enteromorpha intestinalis* is a large colonial form, its name referring to the hollow, tubular coils whose walls contain large numbers of cells.

STONEWORTS (*Charophyta*)

These are larger plants than the algae, and often form dense beds of vegetation, which are always submerged. The main stems have many thread-like branches arranged in circlets at regular intervals. The fruiting bodies have a characteristic form, and are found in the forks of the branches. *Chara* and *Nitella* are the best-known members of this group.

LIVERWORTS and MOSSES (*Bryophyta*)

Although these are mainly land plants, they grow chiefly in damp places, because they lack both adequate roots to absorb water from the deeper layers of the soil, and suitable tissues to conduct the water about the plant.

Liverworts

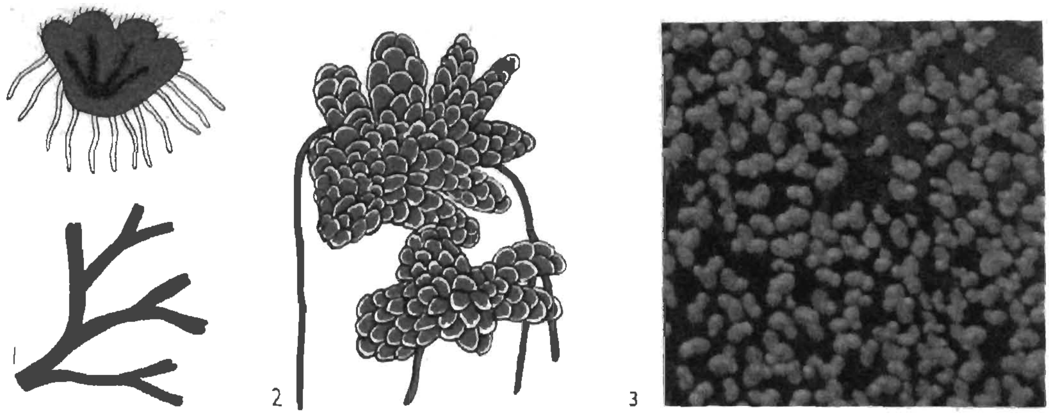
These consist typically of flat, green, branching, leaf-like 'thalli' which creep over damp ground, to which they are anchored by thin, thread-like filaments which do poor service for roots. There are, however, two forms which are truly aquatic, and float at the water surface: *Riccia* has a small, very narrow, repeatedly forked thallus, while in the much less common *Ricciocarpus* the thallus is short, broad, and four-lobed, with air-bladders on the underside which help to keep it afloat.

Mosses

The great majority of mosses are plants of the land or damp ground, but a few are aquatic; the spongy *Sphagnum* found in bog-pools, and *Fontinalis* found in rivers, are important examples.

FERNS and HORSETAILS (*Pteridophyta*)

On the whole, more ferns than liverworts and mosses are adapted to land life, but a few exceptions grow in fresh water.



Plants which float on the surface. 1. *Liverworts.* 2. *Water fern.* 3. *Lesser Duckweed*

Ferns

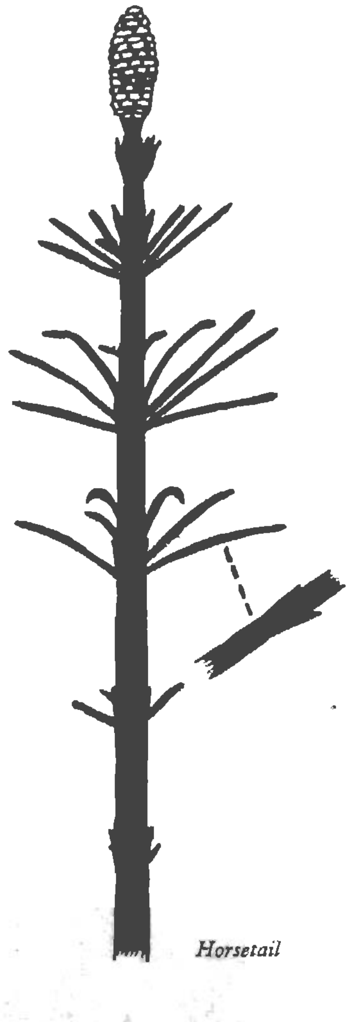
The quillwort (*Isoetes*) and pillwort (*Pilularia*) are uncommon or easily missed, and the only other aquatic form is the conspicuous and curious water fern (*Azolla*), a small floating plant forming a beautiful mauve-green blanket on the surface of water, after the manner of duckweed.

Horsetails

These peculiar plants have segmented stems and branches. Each segment is set in a sheath at the tip of the one beneath, and can easily be pulled out. *Equisetum limosum* is the only really aquatic species; its stems sometimes have branches but are often without them.

FLOWERING PLANTS (*Angiospermae*)

All the larger and more familiar water plants belong here. There are so many of them, showing such diverse structure, that even a brief account of them would require more space than can be spared here. Several examples have been figured earlier in this book in connexion with general topics (see, for example, pp. 31, 39, 51). Duckweeds (*Lemna*) are flowering plants, although the structure is so simplified and the flowers are so insignificant that one would not think so.



Horsetail

SUGGESTIONS FOR FURTHER READING

THERE are two kinds of books dealing with the life in fresh water: those that are concerned with the general biology and life of the animals or plants, and those which help us to identify them. A few books attempt to cover the two purposes; among these are Mellanby's *Animal Life in Fresh Water*, which covers all the groups of invertebrate animals, Clegg's *The Freshwater Life of the British Isles*, covering all groups, and Ford's *Pond Life*, which is brief but also covers a wide field.

Of the general biological works, *Life in Lakes and Rivers*, by Macan and Worthington, is both entertaining and authoritative, and although it contains the outcome of much serious scientific research it can be read with interest by anyone with a taste for scientific natural history. The same is true of Carpenter's *Life in Inland Waters* which is almost confined to animal life, and of an American book with an almost identical title, *Life of Inland Waters* by Needham and Lloyd, which extends to plants as well. Ray Palmer's *Marvels of Pond Life* and Furneaux's *Life in Ponds and Streams* are more popular; the latter has much to recommend it, including useful information about the keeping of aquaria. Other biological works are concerned with limited groups; Arber's *Water Plants* is a splendid book, with a wealth of detail on the life and adaptations of all the British (and some foreign) aquatic flowering plants. Miall's *Natural History of Aquatic Insects* is a classic among biological books, describing in great detail and in the most interesting style the life and life-histories of a limited number of carefully selected types of insects; it is old (first published 1895), but will always be worth reading. Calman's *Life of Crustacea* is comparable, but includes marine as well as freshwater types. Another interesting group of animals, the Amphibia, are the subject of an excellent volume in the New Naturalist series, Smith's *The British Amphibians and Reptiles*.

If you collect and study animals and plants yourself instead of or, better still, as well as reading about them, it will not be long before you are wanting books to identify your captures. Freshwater animals, and to a lesser extent the plants, belong to a number of different groups, and there is no such thing as a book which covers everything in detail. Flowering plants can be identified from any of the well-known 'floras', but the simpler plants are difficult. The algae can be identified up to a point with *British Freshwater Algae* by West and Fritsch, but it is too advanced for the average person to use. A very useful work is *Freshwater Biology* by Ward and Whipple, which covers all the smaller organisms, but, since it deals with American species, only approximate identifications can be made of British material; however, the numerous drawings are very helpful.

Works on the various groups of animals are scattered and too numerous to list. Several groups are covered by the Scientific Publications of the Freshwater Biological Association (water-bugs, stoneflies, mayflies, alder-flies and their relatives, buffalo-gnats, water-fleas, and water-snails). Several of the Ray Society monographs deal with aquatic groups: Balfour-Browne's two volumes on *British Water Beetles*, and Lucas's *The Aquatic (Naiad) Stage of the British Dragonflies* are among them; for the adult dragonflies Miss Longfield's *The Dragonflies of the British Isles* is the most easily available book. For vertebrate animals the well-known *Wayside and Woodland* series is excellent, and includes volumes on birds by Coward, and on fishes by Travis Jenkins; *Animal Life of the British Isles*, by Step, covers the mammals and Amphibia, but is rather out of date on the latter.

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